LIMNOLOGY AND THE MANAGEMENT OF THE FRESHWATER PONDS

OF CAPE COD NATIONAL SEASHORE

National Park Service Contract No. CX-1600-5-0006
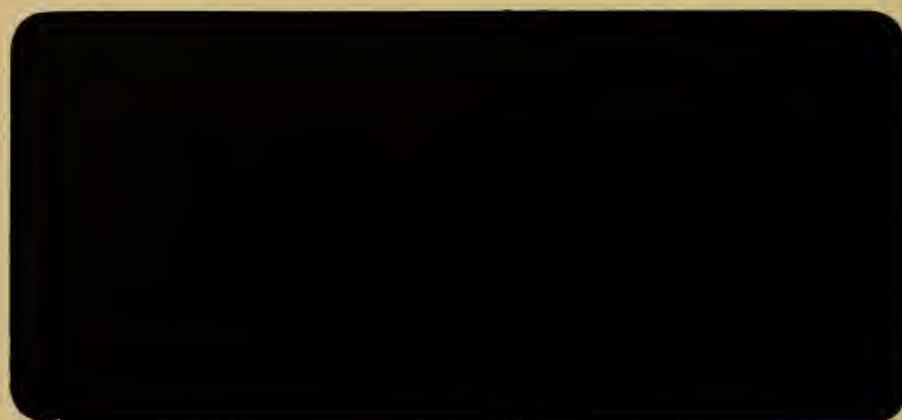
Final Report

NATIONAL
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NATIONAL PARK SERVICE
COOPERATIVE RESEARCH UNIT

INSTITUTE FOR MAN
AND ENVIRONMENT
University of Massachusetts at Amherst

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STATEMENT FOR MANAGEMENT

PROBLEM STATEMENT

Background. One of the most difficult problems in resource
management is the detection and control of human interference with
natural ecosystems and the natural processes (such as community
succession) that occur within them. Difficulties may also arise when
preservation of a natural feature requires control of the rate of
succession to either achieve or prevent the establishment of a mature
natural system. In the case of aquatic succession in freshwater
kettle ponds, for example, there is little question but that the main
objective must be to reduce activities which disturb the natural
pattern of pond succession and speed the evolution of clear lakes to
turbid, weedy ponds and premature obliteration.

Natural Pond Succession. In lakes formed by glaciation, there is
an initial period of heavy erosion and leaching of plant nturients
from exposed soils of the watershed. Consequently, algal productivity
is high in the lake basins because of the abundant supply of nutrients.
As a cover vegetation becomes established, erosion is controlled;
without erosion the lake's source of nutrients is ultimately the
weathering of minerals, soils, and tills of the watershed and input
from atmospheric sources. The products of weathering are also largely
controlled by terrestrial plant communities so that only small amounts
usually enter streams and lakes, dictating limited growth of aquatic
algae and plants. Thus for many temperate deep lakes the initial
phase of high productivity is short-lived and followed by many
thousands of years of stable, low levels of plant productivity--a
period of trophic equilibrium (Hutchinson 1973). Inevitably, however,
and dependent on watershed characteristics and basin morphometry, the
sedimentation of eroded or internally synthesized materials will fill
significant portions of the lake basins. And as the basin size
decreases, plant nutrients begin to accumulate in the water column and
in the sediments and recycle more efficiently, allowing higher produc-
tivity levels. Higher productivity in turn increases sedimentation of
rich organic material, which fills the basin and increases oxygen
demand. When dissolved oxygen is depleted in deep waters, anaerobic
sediments regenerate significantly more nutrients, further favoring
plant growth. Thus the process is self-enhancing, culminating in
marsh and eventually woodland.

Cultural Eutrophication. The extended equilibrium phase of this
natural sequence is now frequently altered by man's activities. In
recent times many lakes, especially the clear (unproductive) ones,
have been sought out as homesites, campsites, recreation areas, etc.,
by an expanding and affluent human population. Human disturbance of
the watershed (whether by farming, lumbering or urbanization) often
disrupts the terrestrial soils and vegetation. Weathering rates may
then increase, terrestrial nutrient recycling efficiency decreases,
and nutrient leakage to streams and lakes accelerates.

Often nutrients from outside the watershed are added, such as fertilizers, foodstuffs (and wastes), and phosphate-based detergents. This increase in nutrient input stimulates lake productivity as algal (phytoplankton) growth in the open water, as scums and algal mats, or as dense masses of aquatic weeds (macrophytes) in shallow water. Often massive outbreaks of algae ("bloom") cause harmful side effects (fishkills, odors, intestinal disorders, etc.). Macrophytes interfere with swimming, fishing, boating, and visual enjoyment. The accelerated state of rapid sediment accumulation occurs prematurely in the lake's natural cycle, rendering the lake less suitable for certain floral and faunal types, as well as for some human uses. Man's enhancement of lake aging--an acceleration of natural changes--is called "cultural eutrophication." Cultural eutrophication is a widespread problem in North America and Europe and has received a great deal of attention recently. Since the symptoms are subtle and gradual over long periods, it is important that management be aware of the problem long before conditions reach the level of public dissatisfaction.

Although Cape Cod (CACO) National Seashore is spared the immediate environmental problems associated with industrial or heavily developed watersheds, the acceleration of nutrient input from nonpoint sources related to many recreational activities and residential areas without benefit of closed sewerage systems is a potential threat to resource preservation, and specifically to the exquisite kettle ponds within the Seashore.

PROBLEM IDENTIFICATION

Local citizens have commonly believed that the freshwater ponds are sources of ear and throat infections and are "polluted." Preliminary indications of pathogenic bacterial contamination as well as excess nutrient input (Doolittle 1974) led to intense public concern, which in turn prompted this study. The study objectives were to assess the deterioration of water quality, collect baseline water-quality data, and provide supporting interpretive information for the simultaneous medical microbiological investigation of the public swimming areas (see Ortiz 1976; Ortiz et al. 1977).

PROBLEM EVALUATION

Many of the preliminary indications have not been borne out. For example, the interpretation of many as to the presence of beta hemolytic streptococci could not be verified. Some natural bacteria cause hemolysis of red blood cells but are not pathogenic to man; they are certainly less devastating than beta hemolytic streptoccus. A standard (and required) confirmation of the presence of beta hemolytic streptoccocci has proved consistently negative over two summers of research (see Ortiz 1977). The ponds do, however, show the presence of certain human pathogens, which apparently are washed from

swimmers and persist for an undetermined period. Hence, high swimmer-
levels produce detectable pathogen concentrations. However, contami-
nation levels are consistantly below USPH standards, indicating that
ponds are reasonably safe for swimming. Since a sizeable fraction of
the average population normally carry such pathogens without symptoms,
it may simply be that freshwater in the ear passages, for example,
favors the growth of, or lowers resistance to, pathogens such as
Pseudomonas aeruginosa already present on the body of some swimmers.
This would be the basis for the commonly held local belief of
"polluted" ponds.

The levels of phosphate in the ponds reported by Doolittle (1974)
are very high (ca. 1 mg liter $^{-1}$) for natural waters and are appar-
ently in error. It is not likely that washing activities (with soap
or shampoo) will satisfactorily explain his high values, as soaps do
not contain phosphorus. As a rule, however, soaps and detergents do
have adverse effects on pond ecology and aesthetics and should be
prohibited.

Nutrient loading in these ponds is a subtle problem and a very
difficult one for those charged with resource preservation. Gradual
increases in nutrient flux from the watershed or outside sources
slowly degrade water quality over periods of years or decades. They
are thus difficult for park management to detect unless sensitized to
the problem or until conditions provoke public dissatisfaction.

Presently, quality in CACO ponds is still high, although several
ponds show signs of, or already have reached, a stage of eutrophy.
Gull, Great (T)*, Ryder, Higgins, and Duck are the most adversely
affected. Sedimentary pigment profiles indicate that increased
productivity is a relatively recent phenomenon, probably associated
with human activities (see Ludlam 1977).

The nutrients causing cultural eutrophication come from a variety
of sources. Contamination of groundwater by septic systems is one
important source. Although no obvious septic tank failures were
noted on any of the ponds, a plume of nutrient-laden sewage will move
horizontally in a direction determined by the local hydrological
gradient. Septic tanks and the movement of wastes through Cape soils
do not provide nutrient removal.

MANAGEMENT RECOMMENDATIONS

1. Properly designed and placed sanitary facilities should be
constructed at Great Pond (W)** and Long Pond. Duck and Spectacle
Ponds should also have facilities if they continue to have public
swimming areas. The facility at Gull Pond should be examined to
ensure that nutrient-laden seepage is being directed away from the

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*Great Pond (T) refers to the Great Pond in Truro.
**Great Pond (W) refers to the Great Pond in Wellfleet.

pond. The installation of closed systems would seem especially practical (and instructive) at public swimming areas.

2. The heavy use of Gull Pond for swimming should be decreased by whatever amount practical. This could be done by closing the pond one or two days each week (at least one heavy-use day) or by reducing the size of the parking area and daily swimmer load. The Gull Pond parking area is a source of erosion and littered material and this input during heavy surface runoff represents a source of nutrients which should be controlled. Further studies of the apparent nutrient-enrichment phenomenon should be made at Gull Pond. Optimally a hydrologic/nutrient flux model should be constructed.

3. The number of users at the smaller ponds such as Duck and possibly Spectacle should be limited. Dyer Pond is already controlled to an acceptable level by restriction of automobile access. Duck Pond, the best example of a small oligotrophic kettle lake, is a most significant natural resource. Special attention should be given to determining and maintaining a low level of use which will preserve its uniqueness.

4. Great Pond (W) has physical and chemical features which favor recreation. Continued use at present levels is warranted, provided proper preventive management is exercised. Sanitary facilities and the means for suitable access to the beach must be provided. Presently many steep foot paths are travelled and much of the hillside is subject to erosion. Proper structures for control of movement up and down these hills is important.

5. Williams Pond is eutrophic and has become very shallow. The Pond is filling rapidly and supports massive growths of pond lilies and emergent plants. These growths are characteristic of a natural senescent stage and without interference the pond will soon become a marsh. The pond has some historical interest and there are private efforts at "reclaiming" the pond by dredging, pH manipulation, and removal of emergents. Dependent upon jurisdiction, the responsible agency should decide upon the future of the pond and formulate a management plan. Reclamation could be included in the plan, if considered a management goal.

6. Two information campaigns should be initiated. The first should be directed at residents and summer cottage dwellers; the second at visitors swimming at the ponds. Information should explain the processes occurring in the ponds and some effective measures which can be taken to prevent deterioration of the ponds. Almost everyone is interested in preserving or improving water quality in CACO ponds and the benefit of this interest should not be lost. Measures which the public might take include: (a) using only phosphate-free detergents; (b) careful disposal of wastes; (c) control of animal wastes (dog, horse, horse stables, etc.); (d) inspection, cleaning, and improvement of sewage systems and promotion of closed systems wherever possible; (e) control of erosion; and (f) curtailment of use of fertilizers on lawns and gardens.

7. A pond management policy, based on a clear understanding and presentation of the extent of the Service's legal jurisdiction, should be formulated and made available to the public as well as be included in the park's Natural Resource Management Plan. This policy should be pond-specific and describe the management goals and actions necessary for the preservation and use of each freshwater pond. (Some progress has been made in this area by the Cape Cod National Seashore Advisory Commission via its subcommittee on pond management.)

8. Additional research should be conducted to establish the exact relationship of septic tanks to the nutrient levels of Gull, Great (T), Ryder, and Higgins Ponds. New methods for obtaining direct measurements are becoming available and should be applied prior to major management actions such as banning septic tanks in certain watershed areas.

9. An additional study on Duck Pond should be made in order to evaluate the apparent trend and recent complaints of water-quality decline. These studies should lead to a specific management program which takes into account its extraordinary value as a natural resource.

10. The kettle ponds of the Seashore should be monitored for chlorophyll a, during summers, total phosphorus (at overturn), and Secchi transparency as often as possible. Likewise, fecal coliform levels should be monitored during warm summers and heavy swimmer use.

SCIENTIFIC BASIS FOR RECOMMENDATIONS

ABSTRACT

Study objectives relate to water-quality trends in the kettle ponds of the Cape Cod National Seashore, some of which have homesites and heavily used public beaches along their shoreline. The objectives include: (1) limnological characterization of these ponds, thereby establishing baseline data for future comparison; (2) enhancement of a simultaneous study of swimmer-related pathogenic bacteria by providing information relating to dispersion and survival in the ponds; and (3) evaluation of the extent of cultural eutrophication, and formulation of management policy for recreational use consistent with resource preservation.

Dissolved oxygen and dissolved silica depletions, free CO_2, hardness, total and soluble reactive phosphorus, chlorophyll a, pH, conductivity, selected cation, and temperature date are reported. Preliminary phytoplankton species identifications are made, and a sedimentation rate for Duck Pond is estimated. A study of photosynthetic pigment profiles has been completed and reported by Ludlam (1977) as Part B of the study.

The twenty ponds under investigation are all seepage ponds with soft, acidic water. Among the ponds a wide summer range of Secchi transparencies (0.5 m to 14 m), chlorophyll a (0.01 to 100 mg m^{-3}), and total phosphorus concentrations was found. Several ponds (with 10 to 18 m depths) have stable summer stratification -- Long, Gull, Great (T), Ryder, and Round (West) -- and the latter four of these have substantial hypolimnetic anoxia and other characteristics of cultural eutrophication. It is recommended that: (1) proper sanitary facilities be made available at all public beaches; (2) several ponds must be immediately provided with control measures for erosion and septic tank effluent; (3) recreational use must be redistributed on the basis of the vulnerability of each pond to nutrient stimulation of plant growth for long-term preservation of the resource.

INVESTIGATION OF FRESHWATER PONDS OF CAPE COD NATIONAL SEASHORE -- RESEARCH REPORT

Introduction

An investigation of the limnology of the freshwater kettle ponds of Cape Cod National Seashore (see Figure 1) has been completed, and management recommendations have been made on the basis of an initial study.

The objectives of this broad study were four:

1. To establish the present limnologic characteristics of the ponds, thereby generating baseline data for future comparisons;

2. To aid in the interpretation of the results of the bacteriological investigation by Ortiz (1976; Contract No. CX-1600-5-0005 CRU/NPS, Univ. of Massachusetts);

3. To evaluate present conditions in the ponds and to formulate management policies compatible with preservation of the nature of the resources.

Methods and Materials

Early data were taken to assess nutrient levels and the amount of living algae (biomass) during the spring overturn. Subsequent observations were made to sound the ponds, describe the extent of mixing, and follow the development of thermal stratification in the deeper ponds. Data on dissolved oxygen (DO), thermal stratification, algal biomass, etc., were collected throughout the summer along with attempts to monitor phosphate additions from recreational activities. During late summer, surface water current velocities were measured. Surveys of selected characteristics were undertaken in fall and winter, and another series of chemical determination (including total phosphate) were made in the spring of 1976. The summer of 1976 was given to monitoring activity on the most important ponds.

In spring, samples were taken at 1 m depth in the well-mixed, unstratified lakes. When the lakes became stratified, vertical series of samples were taken (with a Van Dorn bottle) over the deepest points (found by depth recorder). Vertical temperature and specific conductivity profiles were also taken with a YSI Conductivity meter with 20 m cable. The Secchi transparency was measured with a 20 cm white disc. The Winkler method (APHA, 1971) was used as the routine method for DO determinations.

Calcium (Ca), potassium (K), iron (Fe), and sodium (Na) ions were determined by atomic absorption spectrophotometry (analyses by Dr. K. Symmes). Single aliquots of samples were analyzed with a Perkin-Elmer 403 atomic absorption spectrophotometer equipped with a

chart recorder. Standards were made fresh within 48 hours (usually within 24) of sample analysis. Concentrations were determined from a linear regression line relating concentration in standards to their respective peak heights on recorder printout. The concentration in samples was calculated from sample peak heights using the appropriate equation. The technical data and the analytical procedures are given in Appendix A.

Ca, Fe, and K concentrations were determined in the same aliquot of sample and Na in a second aliquot. Two sets of standards were used: one containing Ca, Fe, and K and the other containing Na. Standard additions were used to overcome analytic interferences (see Appendix A). The samples and standards contained equivalent amounts of these additions.

A second set of Na determinations were made on samples collected on 27 June 1976. Chloride determinations were also made on these samples using the mercuric nitrate titration method (APHA 1971). This set of determinations was made by S. Danos.

Chlorophyll a concentrations, a rapid measure of phytoplankton biomass, were measured according to the method given by Strickland and Parsons (1972).

Soluble reactive phosphorus (SRP), which corresponds roughly to phosphorus readily available to plankton, was determined according to the method of Mullin and Riley (as described in Strickland and Parsons, 1972). Total phosphorus (as P) was determined in samples which were frozen and stored. Samples were thawed overnight at room temperature before analysis. Analytical procedure follows Strickland and Parsons (1972) with the modifications proposed by Dillon and Rigler (1974).

A tall Ekman dredge (15 cm x 15 cm x 26 cm) was used to collect sediment samples from the deepest areas of several lakes. Subcores were immediately quick-frozen (-20°C) for later analysis of sedimentary pigment profiles by Ludlam (1977). Analysis of changes in the diatom community through the sediment column is in progress.

An estimate of annual sedimentation was attempted by the placement of sediment traps in Gull, Williams, and Duck Ponds. Traps consisted of two Nessler tubes suspended in a plexiglass support (see Soukup 1975). Data are available only from the trap in Duck Pond.

An estimate of the number of cars associated with the recreational use of Gull Pond was made using a traffic recorder (furnished by J. Killian, NPS) at the entrance to the Gull Pond parking lot. The recorder was emplaced on 21 July 1975, and an estimate of the number of passengers per car was made on July 22. Daily numbers were recorded by Paul Thimas (town of Wellfleet).

The volume of flow in the Herring River was occasionally measured. A uniform channel area was chosen and its cross-sectional area computed. To estimate velocity, a small plume of fluorescein dye was injected at mid-depth by syringe, and the travel time of the center of the dye mass was timed by stopwatch over a 3 m distance.

At least five trials were made and averaged for each velocity measurement. Flow (in cubic m sec^{-1} (cms)) was calculated from area and velocity data. Fluorescein dye was also used in Duck Pond to observe current velocities and directions. Water samples which were of interest in terms of microbe dispersion were analyzed by Ortiz (1976).

Periodic samples from swimming areas were analyzed for soluble and total phosphorus in an attempt to detect phosphorus accumulations in waters during heavy swimming use. Soluble phosphorus determinations were done as rapidly after sampling as possible, but usually after 1 to 1.5 hours had elapsed. In 1976 an attempt was made to estimate the amount of phosphorus carried on the body surface of local swimmers, many of whom come directly from nearby ocean beaches to swim in the freshwater ponds (and thereby rinse themselves of seasalts). The method (devised and executed by S. Danos) consisted of measuring the increase in total phosphorus in 12 liters of water used to rinse research workers as they returned from beach areas. Only five subjects were so treated, making the estimate (650 ug P $\pm$ 245 per swimmer) a rough one. The mean value was multiplied by the estimate of the seasonal total of swimmers of Gull Pond to arrive at a value for the relative magnitude of input of phosphorus.

The mass of phosphorus in Gull Pond, both at the beginning and end of the summer of 1975, was calculated by measuring the volume of each 3 m interval (using a contour map plus planimeter) plus the phosphorus concentration for each water layer. An attempt to account for increases in the quantity of phosphorus between spring and late summer was then made. The accumulation in the deepest anoxic waters was assumed to represent phosphorus regenerated from profundal sediments. Although significant input must come directly from the euphotic zone, it is impossible (and unnecessary) to distinguish the direction of input to this zone for present purposes. The phosphorus increase calculated as sediment release (0.0019 g P m^{-2} day $^{-1}$) does not differ greatly from those found in other lakes.

An analysis of the development close to the shoreline of Gull Pond was made (by S. Danos) to arrive at an estimate of the potential phosphorus input from cottage sewerage systems. The data taken include the number of cottages close to the shoreline, mean number of occupants, period of occupancy, type of sewerage facility, presence of laundry facilities, types of detergents used, and distance of sewerage system from shoreline. These data, plus the various estimates from Vollenweider (1968) on human waste contribution of phosphorus, were used to approximate phosphorus input from sewage. These calculations assume that cottages which are further away do not leach phosphorus to Gull Pond. It is also assumed that there is no net loss of phosphorus associated with disposal in coarse sandy subsurface materials (see Dillon 1974).

The contribution of the numerous gulls which rest, wash, and swim at Gull Pond, and from such sources as swimmer excretion, aerosol transport of salt water, pitch pine pollen, and other aeolian sources are unknown and cannot be given even broad approximations at this time; additional work in this area is planned.

Results

Estimates of area and maximum depth are given in Table I. Table I also gives the results of spring 1975 conductivity, pH, chlorophyll a, total phosphorus, and ion determinations. Table II presents total phosphorus, pH, and dissolved silica data from spring 1975.

The relationship between vernal total phosphorus concentrations and maximum pond depth is shown in Figure 2.

Surface temperatures were slightly above 5°C in early April 1975 (see Table I), and with the possible exception of Round Pond (West), all ponds were homeothermal (i.e., well-mixed). Dyer Pond, for example, was still uniformly mixed at 7.9°C as late as 16 April (Figure 3). Gull Pond, however, showed the beginning of thermal stratification on 18 April. The inception of thermal stratification in several ponds of different depths is shown in Figure 4.

A partial list of the major algae of the ponds is given as Table III.

Permanent summer stratification did not develop in shallow ponds (<8m) and was also absent in some deeper ones. For example, Great Pond (W) (15 m maximum depth) did not develop stable thermal stratification, remaining thermally and chemically homogeneous and well oxygenated throughout the summer (Figure 5). Duck Pond also showed a rather unstable stratification (Figure 6), apparently due to light penetration and resultant high hypolimnion temperatures. Gull Pond (Figure 7), Long Pond (Figure 8), Ryder Pond (Figure 9), Great Pond (T) (Figure 10), and Round Pond (West) (Figures 11 and 12) all showed well-developed thermal stratification.

As expected, chemical and biological data reflect physical phenomena within the ponds. Dissolved oxygen concentrations reflected stratification but also significant biochemical oxygen demands; the distributions of dissolved oxygens are compared with the corresponding thermal profiles for several of the stratified ponds (Figures 8-12). Gull Pond, because of its recreational importance, was followed most closely, and Gull Pond DO profiles are given separately in Figure 13. Duck Pond DO profiles for the summer of 1975 are shown in Figure 14.

Nutrient levels in the lower layer of water for Round Pond (West) are shown in Figure 15, demonstrating the recycling of soluble phosphorus typical in anaerobic waters.

Depletions or accumulations of free CO_2, according to whether photosynthesis or respiration was the dominant process within the upper, middle, or lower strata of the lake, are shown for several lakes in Figure 16.

Changes in Secchi disc transparency in several ponds during spring and summer (1975) are shown in Figure 17. The relationship between Secchi transparency and summer chlorophyll a concentration is shown in Figure 18. Several points (those designated by pond names) have not

been included in the calculation of the regression line for reasons given in the Discussion.

Summer chlorophyll a data are given in Table IV. Results of a vertical profile of chlorophyll a concentrations in Duck Pond (samples taken with an electric pump and garden hose) are compared with an earlier study by MacCoy (1958) in Table IV. An analysis of phytoplankton at different depths is given in Table V.

Only one stream of importance is associated with the study ponds. The Herring River drains the complex of Gull, Higgins, Williams, and Herring Ponds. Estimates of flow in the Herring River and the Gull Pond sluiceway are given in Table VI. The placid river, approximately 2 m wide below Herring Pond, has a uniform and shallow channel. Base flow was approximately 0.02 cms. Heavy rains fell before the flow estimate of 26 September 1975, swelling the flow two orders of magnitude. The response to the heavy rainfall was delayed several days, indicating that surface runoff was negligible. Several measurements of flow at the Gull Pond sluiceway are also included in Table VI.

Recreational use at Gull Pond, as reflected in vehicular traffic and by paddle-boat rentals (data from Michael Ferreira, Wellfleet), is shown for the summer of 1975 in Figure 19. The average number of people per car was 4.0. During the hourly bacteriological survey by Ortiz (1976) of Gull and Great (W) Ponds (15-22 August) duplicate samples were analyzed for soluble phosphorus, always within two to three hours of collection. Results for swimming areas as well as undisturbed areas are given in Table VII. None of these samples showed soluble phosphorus accumulations. Total phosphorus data for these same samples are given in Table VIII.

Figures 20, 21, and 22 show the accumulations of total phosphorus in the water column of Duck and Great (W), Gull, and Great (T) Ponds, respectively, during the summer of 1975. Appendix B provides the complete total phosphorus data.

A portion of the development along the shoreline of Gull Pond is illustrated in Figure 23. Only those cottages situated most closely to the shoreline are included in Figure 23 and in later calculations. Additional data on the sewerage systems around Gull Pond are given as Appendix C.

After the 4th of July weekend of 1975 complaints concerning water quality at Gull Pond were received by the town of Wellfleet. Subsequent investigation of the shoreline and weedy areas indicated that a bloom of Anabaena flos-aquae (with few heterocysts) of small areal extent has formed. Quantities of this filamentous alga, along with foams and gull feathers, were found along the beach shoreline, suggesting that onshore winds and surface drift had concentrated the bouyant algal cells as well as the debris. Secchi and chlorophyll a measurements were made on 10 July. Low chlorophyll a concentration and high Secchi transparency in the center of the lake indicated that the bloom did not reflect overall productivity, but rather a localized phenomenon, possibly related to the heavy holiday use of the public swimming area. A similar bloom occured in 1976.

An apparent algal bloom and heavy brown scum in the swimming area of Great Pond (W) was also reported on 21 August 1975 (J. Ortiz, pers. comm.). By sundown the foam and scum had been driven across the pond by the prevailing wind to the spit separating Southwest from Great Pond. I collected samples of this scum for bacterial analysis. A total coliform determination (by S. Sousa, CRU) indicated that bacteria were highly concentrated in this material (>2000 ml^{-1}). No evidence of a large phytoplankton bloom was found in Great Pond (W).

Turbulent water movements are wind-induced and are reflected in the thermal stratification profiles. Turbulent motion is effective in mixing water throughout the depth of an unstratified lake and in the upper, warmer layer (epilimnion) of a stratified lake in summer. This corresponds to the upper 4 - 5 m of the stratified ponds mentioned above. Superimposed upon the random turbulent stirring may be wind-induced surface currents. Surface drift near the center of ponds was in the direction of the wind, and drift velocity responded rapidly to changes in wind velocity (and direction). Observations on subsurface currents were made in Duck Pond, and results are given in Table IX and shown in Figure 24.

The profundal sediment trap placed in the deepest part of Duck Pond was retrieved after one year. The estimate of profundal sedimentation was 16 mg cm^{-2}yr^{-1} (dry weight; 105°C).

In temperate lakes, cooling of the surface waters and strong autumn winds normally result in a complete autumn mixing. In the late September - early October data, mixing is nearly complete in many of the ponds, but not in Duck, Round (West), or Gull. This is also reflected in the dissolved silica accumulations seen in Table X. Here Great Pond (W) shows silica accumulation at its deepest point. Long Pond was nearly homeothermal, indicating that mixing was almost complete there. Gull Pond showed a replenishment of DO at 14 and 16 m, and destruction of the DO accumulation associated with the metalimnetic plate present during the summer. Other fall data are given in Table XI.

Following the complete fall overturn, all depths were replenished with dissolved oxygen.

In the winter of 1975-1976, the ice cover was intermittent, and typical inverted winter stratification was rare and short-lived. Instead a near continuous state of overturn prevailed due to the lack of ice cover and the presence of high wind energy. For example, in mid-February 1976, Gull Pond was virtually homeothermal at least in the 1°C (range 0.8-1.0°C) throughout the 18 m water column. Dissolved oxygen levels remained high. It is likely that temperature stratification and ice cover patterns are highly variable year to year, and there seems to be little danger of winterkill of fish from lack of DO under the ice in any ponds except Great (T) and Ryder, and only then in the coldest winters with extremely long periods of ice cover.

Discussion (Literature Cited)

The study site watersheds are all underlain by old Wellfleet outwash plain deposits, which are characterized by a high content of quartzite stones (see Oldale 1968 for full description). The fine-to-coarse sandy nature of the soils (Latimer et al. 1924) and tills (Oldale 1968) creates exceptionally high permeability and results in the general absence of surface drainage in the area. The almost complete lack of discrete inflows and outflow and the unknown extent and degree of basin sealing (due to accumulation of clay-size sediments within seepage lake basins) make it difficult to determine water and nutrient budgets.

The sandy soil is also easily eroded and this property, along with the exposed nature of the ponds, has led to changes in their shapes and numbers. Some ponds have areas of swamp deposits near their margins, and many have developed freshwater beach deposits. Oldale (1968) indicates that the beach deposits have secondarily divided Higgins from Williams Pond, Slough from Round (E) Pond, as well as Great (W) from Northeast and from Southeast Pond. The separation of the original basins is the result of internal circulation patterns which tend to deposit suspended materials wherever irregularities in the shoreline occur. This process helps to account for the rounded shape of many of the ponds, particularly the large ones. Raisz (1934) states that Gull Pond and Higgins as well as Great (W) and Turtle Ponds were also secondarily separated. The same internal process may be responsible for the occurrence of multiple deep areas in Gull Pond and Great Pond (W). Many of the ponds established secondarily (Williams, Round (E), Northeast, Southeast, and Turtle) are small and shallow. Horseleech, Slough, Spectacle, and probably Kinnacum (not sounded) are also relatively shallow (see Table I).

The formation of these beach deposits and spits is dependent upon the patterns of surface currents. The processes operating here appear to be similar to those postulated to have operated in the formation of the Carolina Bays (Livingstone 1954). These processes imply circular or semicircular current patterns and long-shore currents. In Duck Pond, long-shore currents (as described in Livingstone 1954) were demonstrated during periods of low wind velocity (see Figure 24). In other lakes it has been shown that higher winds can quickly produce higher velocities (e.g., see Langmuir 1938). Even though Duck Pond is small, it is not surprising that gyres were observed, demonstrating that subsurface particle movement is not usually simple and direct. The observation of a vertical component further indicates that in Duck and other similar ponds, the current patterns are more complex than those described by Livingstone (1954). The current patterns are a part of the general stirring of the large volume of water contained within the epilimnion.

Surface currents, subsurface currents, mixing, and stirring have several profound effects on pond ecology. They also have implications in the movement and dispersal of bacteria. Wind drift concentrates scums, foams, algae, and other surface and near surface material.

The blooms in Gull Pond in July are concentrated by wind drift. Stirring by wind-induced turbulence disperses and dilutes subsurface bacterial concentrations and may account for the erratic buildup and decline of pathogens observed in swimming areas (see Ortiz 1976). Pathogens are probably distributed throughout the epilimnion of a lake and possibly deeper. Turbulent mixing allows continued suspension and survival of phytoplankton. This turbulence also suspends phytoplankton remains, and probably bacteria as well, in the epilimnion where they are for the most part destroyed (oxidized) before they enter the hypolimnion or shallow sediments.

It should be pointed out that some of the foams found on the ponds are natural (and harmless) products of higher plants in the watershed. There were, however, other examples of foams and thick scums which seemed to be associated with recreational use or washing activity in Gull and Great (W) Ponds. These were often discolored and thick in consistency; moreover, one bacterial analysis (total coliform) on a scum sample which had crossed Great Pond (W) overnight indicated that coliforms were concentrated in them. It may be that pathogens such as Pseudomonas, Staphylococcus aureus, and others known to be in the ponds (Ortiz 1976) can survive and disperse much more successfully in that medium than in the hypotonic, dilute medium that is the epilimnetic water. This possibility should be investigated further.

The resistant nature of the constituents of the till and outwash results in slow weathering rates. Thus, local groundwater is normally low in mineral content, especially calcium, magnesium, silica, phosphate, and nitrogen. The impoverished soils also contribute to the generally low nutrient content of the groundwater. The high proportion of chloride and sodium, and the Cl:Na ratios which range from 1.8 to 2.1 (see Appendix D), indicate that sea spray (with a Cl:Na ratio of 1.8 for seawater) is a predominate influence on the chemical composition of these waters (see also Gorham 1961).

The homogeneity and resistant nature of soils and till lead to a roughly homogeneous soft, acidic, and poorly buffered groundwater. However, the character of groundwater entering ponds becomes modified by factors such as dilution with rainwater (with its content of atmophilic (especially oceanic) elements), exchange reactions when in contact with clays, addition of nutrients recycled from sediments, changes in ion ratios from selective uptake by lake biota, adsorbance phenomena or precipitation reactions of minerals (e.g., iron) associated with oxidizable organics. As a result, the ponds vary widely in their conductivity, as shown in Tables I and XI. Horseleech Pond stands above the others in mineral content.

Water in the smaller ponds, having greater contact with bottom sediments per unit volume, might be expected ceteris paribus, to have higher conductivity. However, ponds with heavy recreational use appear to show a substantial increase in mineral content through the summer season, compared with ponds less heavily utilized (Table XI). Only the small, undisturbed ponds maintain low mineral concentrations. More data will be necessary to fully understand this trend. Contributions of dissolved minerals from local clay deposits, populations

of gulls, etc., could also be responsible. At present it appears that recreational use and shoreline habitation have the greatest effect on Spectacle, Great (T), Gull, Higgins, Herring, and Williams Ponds. Part of the mineral increase seen in Williams Pond water, which is not used for recreation, is probably due to the addition of lime and other "reclamation programs" undertaken by local residents.

Dissolved silica concentrations in groundwater are low due to the resistant nature of the local tills. Lake levels are naturally low as well. Diatom populations decrease the silica content even further, however. In the late spring, most ponds have silica concentrations (Table II) near or at the levels normally considered limiting to diatoms (0.01-0.02 mg si liter $^{-1}$; see Jørgensen 1957).

Silica levels increased during the summer and fall, suggesting that diatoms did not dominate the phytoplankton community during this period. For example, fall levels are somewhat higher in many of the ponds (see Table X). Silica input may have been from groundwater, dissolution of old diatom frustules in the sediment, and other minor sources. In Duck Pond (Table X) an accumulation of silica occurred in autumn in the deeper areas which have more sediment contact, and a thin zone of diatom activity was found at 14 m. A similar phenomenon was found in Gull Pond. The difference in silica concentration between Horseleech and Slough is interesting and may reflect drainage from localized clay deposits near Horseleech or a critical proximity of Horseleech to the ocean.

Secchi transparency patterns differ among the ponds (see Figure 17). Williams Pond transparency decreased between early spring and then increased in late summer. A sample taken from Williams Pond on 2 June 1975, showed that the low transparency was due to a bloom of dinoflagellates. Chlorophyll a concentration was 104 mg m $^{-3}$ and the pH was greater than 9 due to the high photosynthetic demand for CO_2 (see Allen 1972). The pond remained productive throughout June, but slightly less so thereafter, as indicated by the rise in transparency.

Gull Pond showed a classic pattern of enhanced spring productivity, followed by progressively lower algal biomass during late spring and summer. This pattern was seen in both the transparency and the chlorophyll data. Duck Pond shows an opposite trend (Figure 17).

Duck Pond was extraordinarily clear and unproductive. A June Secchi reading of over 14 m was followed by a gradual decline in clarity. The chlorophyll a measurement made on an August 14 composite sample showed 2.5 mg m $^{-3}$, substantially higher than in spring (Table I). Another sampling series was undertaken on 28 August since July DO profiles showed unexpected depletions within the lower zone (see Figure 14). The major center of productivity was deep (Table IV b). The data taken from MacCoy (1958) at Duck Pond also indicate a center of algal biomass in deep water; although these data suggest that increases may have occurred in the interval, the sampling dates are not comparable. However, MacCoy's work suggests that DO depletions were not present in 1956-57. MacCoy's study will be the basis of a more extensive comparison in the future. *Both chlorophyll a and DO data from Duck Pond do suggest however that productivity has increased*

and water quality declined in deep waters since 1958. Because Duck
Pond is by many accounts, and for several reasons, the most natural
and pleasing pond, special attention should be given to its future
management.

Sakamoto (1968) has given a classification of lakes based on
chlorophyll a concentrations:

$$\text{Eutrophic lakes } 6\text{-}140 \text{ mg m}^{-3}$$

$$\text{Mesotrophic lakes } 1\text{-}15 \text{ mg m}^{-3}$$

$$\text{Oligotrophic lakes } 0.3\text{-}2.5 \text{ mg m}^{-3}$$

According to this classification, the spring chlorophyll a data
indicate that Williams Pond is certainly eutrophic, and Rider, Herring,
Gull and Higgins, Kinnacum and Great (T) are mesotrophic. Duck, Dyer,
Great (W) Ponds are oligotrophic (Table III). Mid-summer chlorophyll
a data (Table IVa) indicate that Round Pond (West) is in the mesotro-
phic-eutrophic range.

Dillon (1974) has tentatively outlined a classification of poten-
tial lake recreational use, based on chlorophyll a levels (Table XII).
According to this classification, most Seashore ponds are suitable
for body-contact recreation, but Williams, Rider, and possibly Herring
Ponds are now most suitable for warm-water fisheries.

Secchi transparency has long been known to be a simple, rough
measure of algal biomass or chlorophyll a. The relationship between
Secchi transparency and chlorophyll a certainly holds true for Sea-
shore ponds (as illustrated in Figure 18), and Secchi transparency
could be developed into a practical monitoring tool for park manage-
ment personnel. Further data to establish whether the relationship
is linear or curvilinear (see Dillon 1974) are needed. Inclusion of
the data points from Duck and Great (W) Ponds would give a curvilinear
function. However, the variability among points at the low end of the
chlorophyll a range demonstrates that the relationship is not a pre-
cise one. Part of the scatter is due to the existence of the meta-
limnetic concentration of algae. The depth of this algal plate influ-
ences the Secchi reading and the proportion of tube sample containing
the photosynthetic material. Thus, variability will be high because
standing crop and light extinction are not necessarily distributed uni-
formly over the euphotic zone in a stratified lake.

A second factor which strongly influences the Secchi-chlorophyll
a relationship is the presence of re-suspended inorganic or organic
sedimentary material. An example is Spectacle Pond on 18 July 1975.
On that sampling date a high level of swimming activity had roiled
bottom sediments, giving a muddy appearance to the water. Trans-
parency was, therefore, diminished but was not a function of phyto-
plankton biomass. Because of these interferences the data from Duck,
Great (W), and Spectacle ponds were not used in calculating the linear
regression equation (y = 9.09 - 0.56x) of Secchi transparency (y) on
chlorophyll a (x) in Figure 18.

As mentioned above, swimming reduced the transparency of Spectacle
Pond, although re-suspension of sediment is only a temporary phenom-
enon. However, such activity, especially in a small shallow pond,
might serve to enhance nutrient recycling. Since sediments and inter-
stitial waters are a repository for nutrients removed from the euphotic
zone (by dying, sinking plankton) it may be that nutrient recycling
is significantly enhanced. On the other hand, sediments shallow
enough to be disturbed by swimmers are normally reworked by wind-
induced turbulence anyway, so that the swimmer effect may be inconse-
quential. Spectacle Pond does not seem overly damaged even though it
is heavily used for swimming.

Depletion of DO in the hypolimnion can be an indication of cul-
tural eutrophication. In 1921, Nipkow demonstrated that human occu-
pation of the shoreline of Lake Geneva resulted in subsequent anoxic
conditions within the hypolimnion. Many temperate lakes now show
similar symptoms, in apparent response to cultural eutrophication.
The exact mechanism responsible for initiating a rapid rate of oxygen
depletion is obscure, but the immediate cause is an excess of oxi-
dizable organic matter delivered to deep water and sediments. The
source of the organic matter is normally the euphotic zone, the well-
lit upper layer of the lake where photosynthesis occurs. Several
factors involved in eutrophication might increase the amount of or-
ganic material entering the deeper waters. For example, if diatoms,
which are a preferred food source for some zooplankters, are replaced
by filamentous blue-green algae, which are not heavily grazed, a
greater proportion of the primary productivity is available for de-
composition in the hypolimnion. Low levels of silica, as seen in
Seashore ponds, are thought to be responsible, in part, for the
replacement of diatoms by blue-green algae (see Soukup 1975). High
sodium and low nitrogen relative to phosphorus would also favor blue-
greens. A second factor is that massive or sporadic availability of
organic material, as in blooms, overwhelms normal predation or other
oxidizing processes in the water column (e.g., Kleerekoper 1952).
Again, more oxidizable material would be available to the hypolimnion.
A third possibility is that early in the eutrophication process, much
of the enhanced productivity may occur in narrow zones in deep water;
these metalimnetic concentrations of phytoplankton are sometimes
indicated by the accumulation of DO in the middle regions (metalim-
nion) of a lake. Gull, Long, Great (T), Round (West), and Rider
Ponds (Figures 8-13) show metalimnetic DO accumulations. Upon death,
the cells may sink directly into the poorly lighted, cooler, oxygen-
poor hypolimnetic waters. This route circumvents the oxidation
process acting on cells dying in shallow waters, and may result in
more oxidizable organic matter reaching the hypolimnion.

Substantial DO depletions occur in the hypolimnia of Gull,
Round (West), Great (T), and Rider Ponds, and to a lesser extent in
Duck Pond. Lack of oxygen is of considerable importance in the
economy of a lake. Obviously, DO is needed for the support of aero-
bic fauna. Of equal importance is the fact that several important
nutrients, including phosphorus, are released from the sediment when
the overlying water becomes anoxic and ferric compounds are reduced

to ferrous ions (e.g. see Figure 15). The accumulation of phosphate
ions in lower waters may be significant (see Table XIII and below) and
it is thought by some that those ions are circulated into upper layers
at fall or spring overturn (Fast et al. 1973).

Although many factors may determine levels of plant growth in
these ponds, phosphorus is often a key element in controlling fresh-
water productivity because it is essential to life processes yet geo-
chemically rare (Hutchinson 1973). It is also the element presently
most susceptible to management.

Within a nutrient-poor land area with a roughly homogeneous dis-
tribution of vegetation types it might be expected that lake phosphorus
levels are low with variations related to basin size and/or depth.
Larger volume ponds would have a greater dilution factor for incoming
nutrients and relatively less contact with sediments. Phosphorus
levels do vary among ponds in this fashion; a plot of spring phos-
phorus levels against maximum depth (Figure 2) suggests the expected
relationships of increasing nutrient concentration as depth decreases.
A more suitable plot would be total phosphorus as a function of mean
depth, but contour maps (and volumes) are not available for all ponds
as yet. Nevertheless, a suggestion of excess phosphorus loading is
present in Figure 2, where the values for Gull Pond are noticeably
higher than expected. Indeed Gull Pond, because it is the largest
and deepest lake of the group would a priori be expected to be quite
unproductive and clear, as is Duck Pond or Great Pond (W).

A comparison of Figures 20 and 22 illustrates the differences in
total phosphorus concentration, as well as the different magnitudes
of change in total phosphorus, between two clear lakes (Duck and
Great (W) ponds) and Gull and Great (T) Ponds throughout a summer.
These differences reflect significant excess nutrient input to and
recycling in Gull Pond and Great Pond (T). These phenomena, as they
occur in Gull Pond, are given a closer examination in Table XIII
with the relative magnitude of input shown where possible.

Under the oxidizing conditions usually present in surface waters,
phosphorus is absorbed on hydrous ferric oxides. This may occur at
the sediment-water interface, or, most significantly perhaps, as
groundwater seeps through basin sediments into the pond. This mech-
anism may provide a strong buffer mechanism against increasing produc-
tivity through groundwater contamination and might account for the
long-term maintenance of high clarity in many of the ponds. However,
when the deep water becomes anoxic, sedimented ferric compounds are
reduced and ferrous ions and the associated ions (including P) are
released into the water. Substantial DO depletion, as discussed
earlier, occurs in the hypolimnion of Gull Pond (see Figure 13).

Additional loading of phosphorus may come from a variety of
sources (see Table XIV). Contamination of groundwater by septic
systems is probably an important source. Although no obvious septic
tank "failures" were noted on any of the ponds, nutrients in sewage
slowly seep down the hydrological gradient in a plume which is usually
less than 1 m greater in width than the septic-cesspool facility

(Kerfoot 1974). In the porous soils of the area, movement is relatively fast and sorption of nutrients such as N and P is probably minimal. Also, the use of phosphate-based detergents effectively doubles the per capita phosphorus loading (Vollenweider 1968); the recent decline in phosphate-based detergent use will be helpful but any beneficial effects will be delayed. Half of the Gull Pond residents still use phosphate-based detergents (see Appendix C).

Another source of nutrients is related to recreational use. Swimmers can add phosphorus, nitrogenous compounds, and other nutrients in significant quantities by urination and defecation along the shoreline. Soluble phosphorus, if added with wastes, is probably taken up quickly by plankton; this source was reflected only occasionally in total phosphate levels (see Table VIII). Since water currents and turbulence are efficient dispersal factors (for pathogens as well), the effect of swimmers will be incremental, and detrimental, over a large volume of water, and thus difficult to detect. The magnitude of phosphorus transport on the body surface of swimmers is not insignificant but probably should not be a focal point of management actions.

Since only one pond (Gull) has public restroom facilities, a significant amount of human wastes is almost certainly entering other swimming ponds, some of which are used by an excess of 1000 bathers on peak days. This represents a threat to public health and to long-term preservation of water quality and should be corrected immediately. In addition, the septic tank sanitary facility at Gull Pond should be examined to determine whether the hydrological gradient permits nutrient-rich seepage into any part of the pond. Many such facilities are constructed with only public health threats (and sanitation codes) in mind; nutrient loading has usually not been considered.

Another source of nutrients is the large gull population characteristically seen bathing and resting on several of the ponds. Many aquatic birds do not represent nutrient sources because they feed primarily in or around the ponds. The gulls at Gull Pond and Great Pond (T) feed either on the ocean or at nearby landfills. They represent an airborne route for transporting extra-watershed nutrients into the ponds. The per capita contribution of a gull, although probably less than that of a Canada goose (see Table XIV) and somewhat proportional to body weight (Manny et al. 1975) is significant for these ponds where hundreds of gulls visit each day. Improved control of garbage availability at nearby town landfills might reduce this source of nutrient input to these ponds by reducing the number of gulls in the area.

A similar situation is found in Great Pond (T) except the accumulation is greater (i.e., the problem is worse). The data of Ortiz (1976) also indicate curiously high levels of Staphylococcus aureus. These two lines of evidence suggest that the pond is receiving significant amounts of wastes.

The change in total phosphorus in Duck Pond over the summer (Figure 20) is less extensive and the surface waters are still extraordinarily clear. Secchi readings 14 m are found in June but clarity declines in July and August (see above). However, the significant and unexpected DO depletions, the increased chlorophyll a concentrations found on 28 August 1975 especially the values at the lowest depth indicating a sizeable biomass of a blue-green (see Table V), indicate cause for concern. Although more work is needed, it appears that Duck Pond has responded to recreational use in a very subtle fashion -- one that escapes detection by normal observation. Although the watershed is intact, the surface waters are impressively clear, and the Secchi transparency is high; there apparently has been a significant increase of nutrients and algae in the deeper waters over the last 20 years (see MacCoy 1958). It is important that more work be done to verify the extent and understand the causes of these changes. The manner in which this unproductive seepage lake responds to recreational use by cottage visitors, to Wellfleet beach area swimmers, and to subtle change in the watershed, the atmosphere, and other nutrient transport pathways must be known in order to fashion an effective management policy for preservation of this significant resource.

Generally, control of nonpoint nutrient sources is difficult, and it is significant and problematic that lack of control will not lead to rapid devastation but to more subtle and gradual decline. Only in the latter stages of cultural eutrophication do massive weed beds or algal blooms severely interfere with recreation in these ponds, leading to public calls for action. However, the early lack of dramatic events does not warrant neglect. Effective and prudent management requires preventative management. As Vollenweider states (1968, p. 141):

> There is no doubt that the elimination of local
> sources of pollution can bring about a considerable
> improvement in the overall condition of a lake,
> regardless of its surface area and its depth. How-
> ever, it is to be feared that deep lakes in which
> over-enrichment is already pronounced cannot be
> restored to their original state, and that recourse
> to specific reclamation measures will do little to
> achieve speedy improvement of the overall condition
> of such lakes (i.e., as regards both the epilimnion
> and hypolimnion).

Specifically, management for long-term preservation of these ponds, and especially Gull Pond, should consist of minimizing watershed disturbances (e.g., from construction, development, and beach operations), minimizing septic tank seepage (at least through bans on P-based detergents, and adoption of closed-system sewage disposal alternatives), regulating the numbers of swimmers, providing sanitary facilities for each swimming area, minimizing shoreline erosion (especially from swimmer traffic), and informing the public of the vulnerability of these natural resources. It is evident that larger communities of aquatic plants are present in Great (T), Ryder, Herring, and

Williams Ponds (as well as other smaller ponds). There also appears to be a significant recent increase in the pond lily population at Gull Pond. An inventory and mapping survey should be made as soon as possible in order to assess future changes. Often there is pressure for weed control when aquatic plants interfere with swimming, fishing, or boating. It is imperative that weed management policy be based on the prophylactic control of nutrient input and on corrective measures that do not aggravate the problem. Thus, the use of herbicides for weed control, at best an expensive proposition with unpredictable results and untold effects on natural aquatic systems, must be avoided.

While present management options give little cause for optimism as far as corrective measures are concerned, alert preventative management will preserve park recreational waters, in many of which the level of water quality is high and problems are still avoidable.

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Table I

Estimates of maximum depth, area, and levels of pH, conductivity, total phosphate and selected ions of the Cape Cod National Seashore ponds. (W) denotes Wellfleet ponds. (T) denotes Truro. East and West is used to distinguish the two Round Ponds in Truro. An asterisk denotes these ponds with public swimming areas. All levels were observed in spring 1976 except Chlorophyll a (spring 1975).

	max. observed depth (m)	Area (ha)	Specific Conductivity (umhos cm^{-2})	pH	Chlorophyll a	Total Phosphorus (as ug P Liter^{-1})	Ca	Fe	K	Na
Duck *	18.2	5.1	63	5.4	0.1	4	1.4	0.05	0.7	13.1
Dyer *	10.5	4.8	55	5.7	0.9	8	n.d.	n.d.	n.d.	n.d.
Great (W) *	14.9	17.8	79	6.7	0.0	4	1.1	0.09	0.9	14.9
Long *	15.5	15.0	68	7.0	1.8	5	1.4	0.09	0.9	11.8
Turtle	ca. 2	1.6	63	6.7	3.6	16	1.4	0.09	0.7	9.8
Northeast	n.d.	1.7	71	6.6	1.5	9	n.d.	n.d.	n.d.	n.d.
Southeast	4.3	1.1	71	6.7	1.4	16	1.8	0.04	0.8	12.7
Spectacle *	6.8	0.5	73	5.8	2.4	6	1.2	0.04	0.8	13.7
Kinnacum	n.d.	0.8	62	7.0	5.3	9	1.1	0.01	0.5	9.1
Gull *	18.9	44.0	78	5.4	7.6	16	2.0	0.04	1.0	16.6
Higgins *	6.0	11.3	81	6.5	6.4	26	2.0	0.26	0.9	16.7
Herring	4.3	8.1	84	6.5	9.2	24	2.0	0.24	0.9	16.6
Williams	1.9	3.6	97	6.3	18.8	25	2.0	1.31	n.d.	13.1
Slough	8.2	11.9	82	6.8	1.8	9	1.4	0.01	0.7	15.4
Horseleech	4.6	10.0	96	6.4	2.1	12	1.5	0.05	0.9	16.7
Round (East)	7.8	2.6	73	6.2	2.6	7	1.2	0.05	0.8	14.4
Ryder	10.5	8.3	77	6.3	13.3	7	1.3	0.07	0.9	16.0
Snow	7.5	2.3	58	6.4	n.d.	10	0.8	0.08	0.6	10.8
Round (West)	9.3	0.8	51	6.1	n.d.	14	0.9	0.12	0.6	8.7
Great (T)	11.5	7.0	85	6.2	5.0	8	4.9	0.08	0.07	17.2

Table II

Hardness, pH, and Silica levels in the Cape Cod National Seashore ponds at spring overturn (6-19 April) 1975. Silica values in brackets were taken 5-6 April.

	Total Phosphates			
Group I	as ug liter^{-1}P)	PH		Si (mg liter^{-1})
Duck	7	5.4		n.d.
Dyer	r.d.	4.9		0.01
Great (W)	8	5.0		0.03
Long	n.d.	n.d.		n.d.
Turtle	46	5.3		n.d.
Northeast	14	5.0		0.01
Southeast	21	5.4		0.01
Spectacle	14	4.9		0.01
Kinnacum	13	4.9		0.01
Group II				
Gull	19	7.2	(0.02)	0.01
Higgins	n.d.	7.4		(0.01)
Herring	n.d.	7.8		(0.23)
Williams	n.d.	7.2		(0.05)
Slough	8	5.4		0.01
Horseleech	8	5.9		0.23
Round (East)	n.d.	5.8		n.d.
Group III				
Ryder	15.	6.0		1.43
Snow	13.	n.d.		n.d.
Round (West)	n.d.	n.d.		0.00
Great (T)	n.d.	7.6		n.d.
Miscellaneous				
Perch Pond (Wellfleet)	60.	n.d.		1.43
Peck House Well	22.	6.7		n.d.
Rain	n.d.	n.d.		0.00
Gull Pond				
Summer Surface Scum	520*	n.d.		n.d.

(* in filtrate; non filterable fraction 3500 ug P/g dry weight)

Table III

A partial list of algae found in Cape Cod National Seashore

POND	SAMPLING DATE	DOMINANT ALGAE	COMMON ALGAE
Gull	1 May 1975	Asterionella formosa Tabellaria fenestrata	Chroococcus Mougeotia
Duck	26 July 1975	Chroococcus Genicularia	Synura Oedegonium
Williams	30 April 1975	Pediastrum duplex Dinobryon bavaricum	Diatoma Scenedesmus Staurastrum
Spectacle	3 May 1975	Peridinium limbatum	Chroococcus Surirella linearis Tabellaria fenestrata
Higgins	30 April 1975	Asterionella formosa Tabellaria fenestrata Dinobryon divergens	Zanthidium Staurastrum Melosira
Horsebech	16 May 1975	Zygnema Dinobryon divergens	Tabellaria fenestrata Asterionella gracillima
Dyer	16 April 1975	Dinobryon sertularia	Peridinium limbatum
Rider	17 April 1975	Peridinium	Asteronella formosa
Great (W)		Dinobryon	Tabellaria

Table IV

a.) Summer Chlorophyll a concentrations and Secchi transparencies in selected Cape Cod National Seashore ponds.

Date	Site	Chlorophyll a (mg m^{-3})	Secchi Depth (m)
14 July 1975	Great Pond (T)	0.8	8.5
10 July 1975	Williams Pond	14.1	1.4
10 July 1975	Gull Pond	2.6	8.1
15 July 1975	Round Pond (West)	5.9	5.0
17 July 1975	Great Pond (W)	0.8	>11.7
18 July 1975	Spectacle Pond	3.2	3.2
6 August 1975	Round Pond (West)	8.7	5.3
14 August 1975	Duck Pond	2.5	12

b.) Chlorophyll a concentrations (mg m^{-3}) at different depths in Duck Pond, Cape Cod National Seashore, Wellfleet, Massachusetts.

Depth (m)	27 July 1956 (MacCoy, 1958)	28 August 1975 (Soukup, 1976)
0.5	0.70	0.75
4	0.90	2.2
8	0.90	2.0
12	2.3	3.1
15	n.d.	14.2

Table V. Distribution of the most frequently occurring algal genera in the water column of Duck Pond, Wellfleet, Massachusetts, 26 July 1975. (Each value X1000 = organisms/ML).

Algae *	Depth (m)									
	0	2	4	6	8	11	13	14	16	18
Myxophyta										
Chroococcus	800	630	800	710	380	710	2,700	51	25	38
Chlorophyta										
Chlorella	41	190	54	70	10	170	120	0.1	19	35
Tetradesmus	19	0	19	12	45	70	12	0	0	N.D.
Genicularia	0.5	0.2	0.6	0.4	0.9	0.7	0	0.1	0	0.5
Oedogonium	0.1	0.3	0	0.2	0.2	0.1	0.1	0.1	0	0
Pyrrophyta										
Peridinium	0.5	6.4	0	0.1	0	0	0	28	51	90
Bacillariophyta										
Cymbella	1.1	0.7	0.3	<0.1	0.7	1.8	1.1	1.1	0.5	0.3
Navicula	0.5	0	0.2	0.1	0.7	0.6	0.1	0.1	0	0.2
Diatoma	0	0.2	0.3	0.1	0.3	0.4	0.2	0.1	0.1	0.1
Tabellaria	0.1	0	0	0	<0.1	0.6	0.2	0.4	0.5	0.2
Asterionella	0.1	0	0	0	0.3	0.2	<0.1	0.1	0.2	0.4
Nitzchia	0.1	0.2	0.2	0.3	0.2	0.1	0.3	0.3	0	0.2
Surirella	<0.1	0	0	0	<0.1	0	0.1	0	0.1	0.3

* Other genera present: Chlorophyta: Cylindrocystis, Ulothrix; Chrysophyta: Fragilaria, Staurastrum, Chrysophyta: Dinobryon (2 species).

Table VI. Flow data (in cubic meters per second) for the Herring
River and the Gull Pond Sluiceway.

	Date	Herring River	Gull Pond Sluiceway	% of River Flow from Gull Pond*
26	May 1975	0.030	n.d.	---
20	July	0.021	n.d.	---
6	August	0.023	n.d.	---
14	August	0.024	n.d.	---
26	September	0.061	n.d.	---
31	January	0.14	n.d.	---
1	June	0.052	n.d.	---
10	June	0.041	n.d.	---
11	June	0.041	0.024	58%
21	June	0.05	0.03	60%
25	June	0.032	0.014	44%
10	July	n.d.	0.003	
26	July	0.011	n.d.	---
14	August	n.d.	0.005	---

* Gull Pond area is 66% of that of the 4 pond complex.

Table VII

Soluble reactive phosphorus concentrations in selected CACO ponds. Several observations were
made 20 - 22 August for Gull and Great Pond, in both swimming and nonswimming areas

Pond	Sampling Area	Soluble Reactive Phosphate (ug $liter^{-1}$)	Date of sampling and analysis
Great (W)	West shoreline	<10	20 - 22 Aug. 1975
	Swimming area		20 - 22 Aug. 1975
	morning	<10	
	afternoon	<10	
	late afternoon	<10	
Gull	Sluiceway to Higgins Pond		20 - 22 Aug. 1975
	morning	<10	
	afternoon	<10	
	Swimming area		20 - 22 Aug. 1975
	morning	<10	
	afternoon	<10	
	6 m, center of lake	<10	23 Aug. 1975
	16 m, center of lake	<10	23 Aug. 1975
Long	Swimming area	<10	22 Aug. 1975
Northeast	West Shore	<10	22 Aug. 1975

Table VIII. Monitoring Total Phosphate* in heavily swum Cape Cod National Seashore Ponds, Summer 1975.

Gull Pond	19 August		20 August			21 August	
	9 am	11 am	1 pm	4 pm	8 pm	10 am	1:30 pm
Swim Area	8.5	6.2	9.6	6.8	5.6	Pond closed for Construction	
Down-current of Swimming Area	8.4	8.0	-	-	-		
Sluiceway	-	5.1	32.4	7.5	6.4		
Great Pond (W)						Extra Swimming Impact	
Swimming Area	-	5.7	5.4	6.1	5.1	5.6	4.9
Down-current of Swimming Area	-	-	6.3	5.1	2.5	4.2	12.1

* As P ug liter^{-1}; determination in triplicate, according to the methods of Strickland and Parsons (1972).

Table IX

Estimates of subsurface currents (ca. 0.5 m depth) in Duck Pond during August 1975. See Figure 20 for sites and movement of observed currents. Wind data from CRU Weather Station (2.6 Km NNW.)

Date	Current Estimate			Wind Data (km h^{-1})		Comments
		Velocity	Direction	Velocity	Direction	
11 Aug	1.	2.9	NNE	2.5	ENE	Current at 0.5 m was greater than at 1 m (not measured).
	2.	4.3	NNE	"	"	
	3.	2.1	NNE	"	"	
15 Aug	4.	2.0	E	7	from WNW, backing to NNE	From swimming area, along-shore in counterclockwise direction.
	5.	2.5	ENE	"	"	Same as 4.
	6.	2.7	N	"	"	Same as 4.
	7.	2.2	N then W	"	"	Same as 4, then dye moved offshore and downward.
	8.	0	"	"	"	Dye stalled in area next to offshore current area.
	9.	2.0	S then W	"	"	Dye placed to right of stall area; dye moved clockwise then offshore at same point as 7.
	10.	1.5	S	3.5	ESE	At cottage. Dye moved directly offshore and downward.

Table X

Silica concentrations in Cape Cod National Seashore ponds, 23 Sept.-1 Oct. 1975. Where no depth is given, the pond was unstratified and the sample from 0.5 m below the surface.

Group I	Depth (m)	mg Si liter^{-1}	Group II	Depth (m)	mg Si liter^{-1}	Group III	Depth (m)	mg Si liter^{-1}
Duck	4	0.03	Gull	5	0.10	Rider	0	0.05
	8	0.03		10	0.11		5	0.05
	11	0.03		12	0.08		8	0.05
	14	<0.01		14	0.10			
	16	0.53		16	0.42	Snow		0.07
	18	1.53		18	0.57			
						Round (West)	1	0.06
Dyer		0.01	Higgins		1.00		3	0.06
							5	0.06
Great (W)	1	0.13	Herring		2.3		7	0.08
	5	0.13					8	0.72
	10	0.13	Williams		0.13		9	1.48
	14	0.14						
			Slough		0.08	Great (T)	1	0.30
Long	1	0.05					7	0.32
	5	0.03	Horseleech		1.03		9	0.35
	10	0.04					11	0.70
	12	0.07	Round (East)		--			
	14	0.08						
Turtle		0.01						
Northeast		0.03						
Southeast		0.01						
Spectacle		0.03						
Kinnacum		0.18						

Table XI

Fall levels of pH, temperature, and specific conductivity in CACO ponds, 1975.

	Date	pH	Temp $^{\circ}$C	Specific Conductivity (umhos)	Change since spring (umhos)
Group I					
Duck	27 Sep	5.9	19.8	64	1
Dyer	27 Sep	4.5	19.8	59	1
Great (W)	1 Oct	6.6	18.9	75	0
Long T	30 Sep	5.5	19.1	62	4
Turtle	24 Sep	4.7	17.5	52	-1
Northeast	24 Sep	4.5	17.1	64	-2
Southeast	24 Sep	4.8	18.4	64	-2
Spectacle	24 Sep	4.7	18.7	68	15
Kinnacum	24 Sep	4.1	18.3	56	3
Group II					
Gull	27 Sep	5.7	19.1	74	1
Higgins	27 Sep	6.0	19.2	74	4
Herring	25 Sep	5.6	17.7	76	6
Williams	27 Sep	6.0	19.4	78	2
Slough	25 Sep	5.2	18.2	73	-2
Horseleech	25 Sep	5.2	17.3	87	-4
Round (East)	2 Oct	5.6	19.3	68	-3
Group III					
Rider	28 Sep	5.8	19.8	72	-1
Snow	28 Sep	6.0	19.5	51	-1
Round (West)	1 Oct	6.9	19.8	46	-
Great (T)	28 Sep	6.0	19.2	78	3

Table XII

Chlorophyll _a_ levels in a tentative classification of recreational
lakes. Taken from Dillon (1974).

Level 1: 2 mg m^{-3}; for lakes to be used primarily for
body contact with recreation, and where it is
desirable to maintain hypolimnetic concentra-
tions of oxygen in excess of 5 mg l^{-1}. The lake
will be extremely clear with a mean Secchi disc
visibility of >5 m and will be very unproductive.
(Note - The Secchi disc visibility may be lower
in brown water (dystrophic lakes)).

Level 2: 5 mg m^{-3}; for lakes to be used for water recrea-
tion but where the preservation of cold water
fisheries is not imperative. The lake will be
moderately productive and correspondingly less
clear, with a mean Secchi disc visibility of 2
- 5 m.

Level 3: 10 mg m^{-3}; for lakes where body-contact recrea-
tion is of little importance, but emphasis is
placed on fisheries (bass, walleye, pickerel,
pike, maskinonge, bluegill, yellow perch).
Hypolimnetic oxygen depletion will be a common
occurrence. Secchi disc depths will be low
(1-2 m), and there is a danger of winterkill
of fish in shallow lakes.

Level 4: 25 mg m^{-3}; suitable only for warm water fisheries.
Secchi disc depth <1.5 m, hypolimnetic oxygen
depletion beginning early in summer, considerable
danger of winterkill of fish except in deep lakes.

Table XIII. Analysis of the total phosphate accumulation
in Gull Pond for the Summer of 1975. See Figure
5, and text for details of calculations.

Total mass of P, Spring 1975:	80 kg
Total mass of P, Fall 1975:	<u>160</u> kg
Net Increase:	80 kg P
Approximate Contributions to the Net Increase:	
Shoreline cottages (22 within 50 m of shoreline)	22 kg*
Swimmers (estimated as 20,000 for this period)	
body surface source	13 kg
metabolic wastes	?
(1.3 g P capita day^{-1} as urine)	
(0.22 g P " " as feces)	
Sediment regeneration in hypolimnion	10 kg
(anaerobic; ca. 0.0019 g P m^{-2} day^{-1})	
Seagulls (at hundreds of gull visits/day^{-1})	?
Allochthonous input	?
(e.g., as Pitch Pine pollen)	

Table XIV. Estimates of the contributions of several sources of N and P:

Source of Nutrient	Mass of material (kg yr⁻¹)	N		P		Reference
		kg cyr⁻¹	g cd⁻¹	kg yr⁻¹	g cd⁻¹	
Rainfall*	1 x 10⁶	0.55	--	0.075	--	Miller 1955; Dillon 1974
Human wastes (physiological) a. fecal material	48	0.77	2.1	0.08	0.22	Van Vuran 1948; Buckstegg 1966
b. urine	437	4.3	11.9	0.47	1.3	
Human wastes (household)	275,000–550,000***	4.4	12	0.82–1.1	2.25–3**	Vollenweider 1968; Kerfoot 1975
Wildfowl a. Duck (domestic)	-	0.95	2.6	0.4	1.1	Sanderson 1953
b. Canada geese (x̄ body wt = 2.56 kg)	11.96	0.51	1.4	0.16	0.44	Manny, Wetzel, and Johnson 1975

*denotes units of g m⁻² yr⁻¹
**denotes the high range of P content of sewage which has other loadings, especially P-based detergents
***denotes the average rate of cesspool release, see Kerfoot 1975.

Data of Van Vuran 1948, Buckstegg 1966, Miller 1955, and Sanderson 1953 were quoted from Vollenweider 1968 and not seen.

Cape Cod National Seashore Ponds
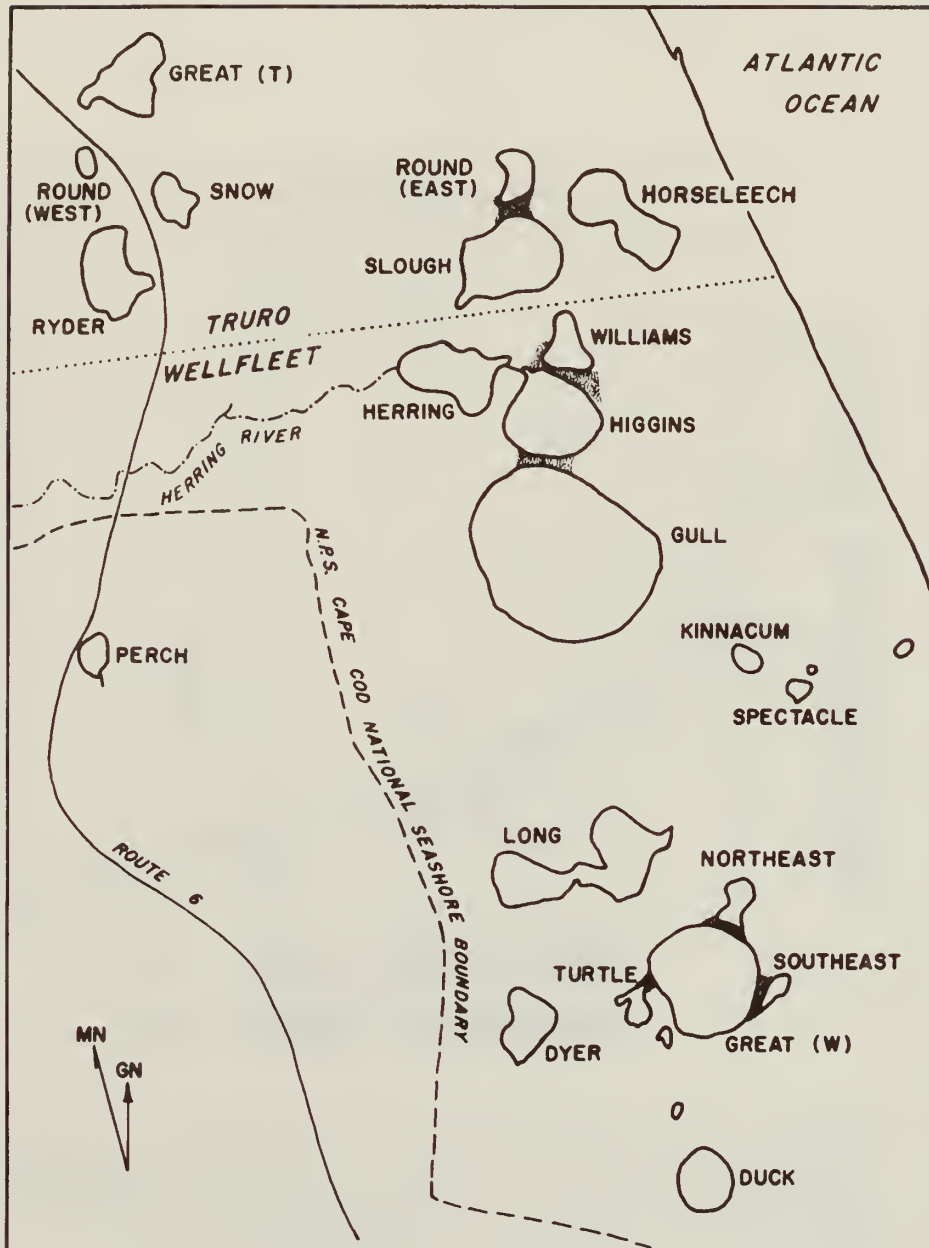
Figure 1. The ponds under investigation in Cape Cod
National Seashore. Stippled areas indicate freshwater
beach deposits, which have secondarily partitioned the
original lakes (See Oldale 1968; Raisz 1938).
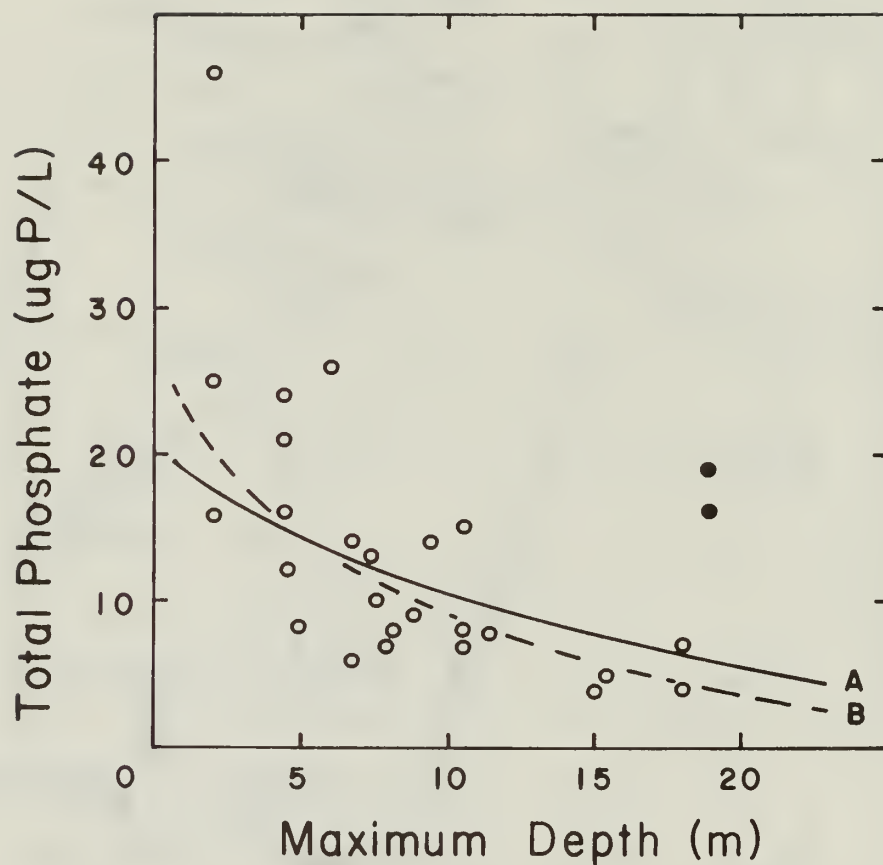
Figure 2. The relationship of total phosphate
concentrations to maximum depth during spring overturn
(1975 and 1976 data) in Cape Cod National Seashore
kettle ponds. Closed circles represent values for
Gull Pond. Line A generated from the equation
$y = (19.5) e^{-0.06x}$, $r^2 = 0.28$; Line B was calculated
after deleting the two Gull Pond data points which
gave the equation $y = (24.9) e^{-0.1x}$, $r^2 = 0.57$.
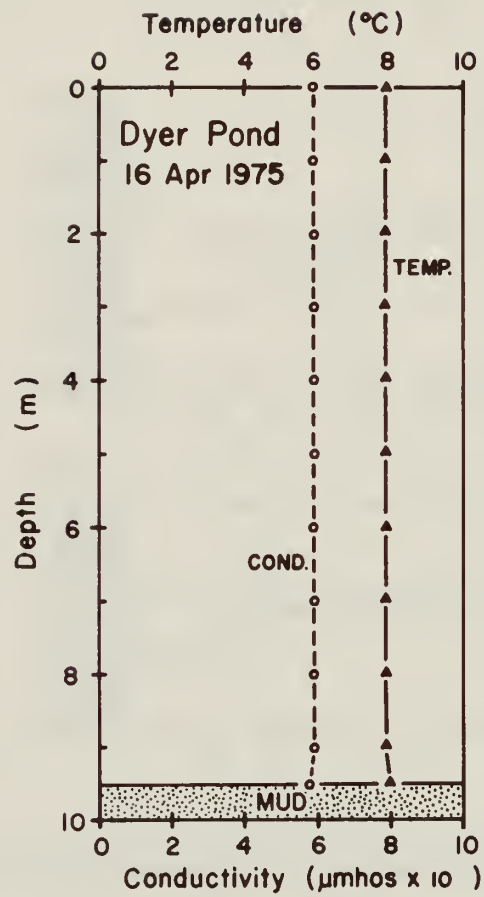
Figure 3. Temperature and conductivity profiles in Dyer Pond.

48
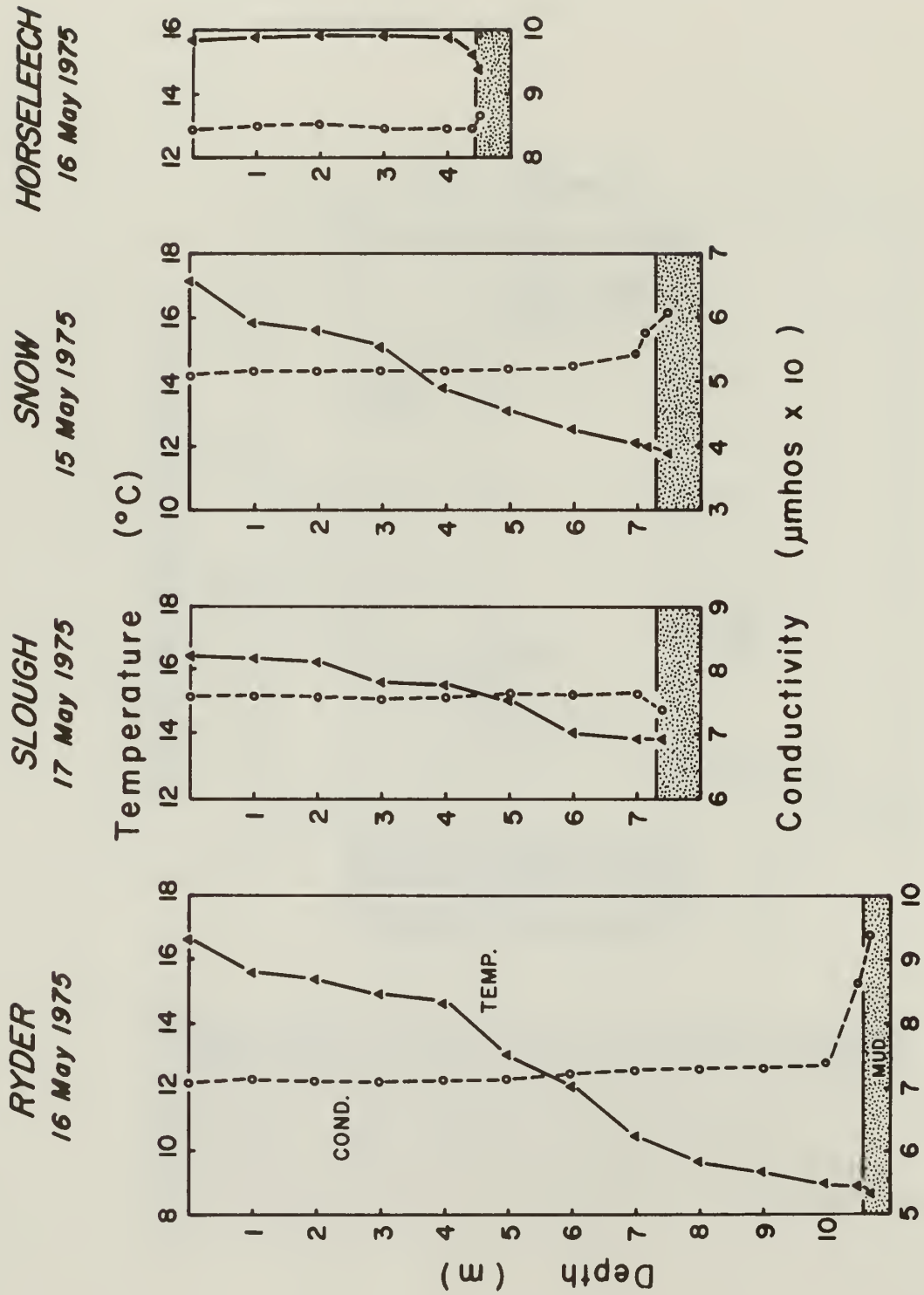
Figure 4. The inception of stratification in several CACO ponds.
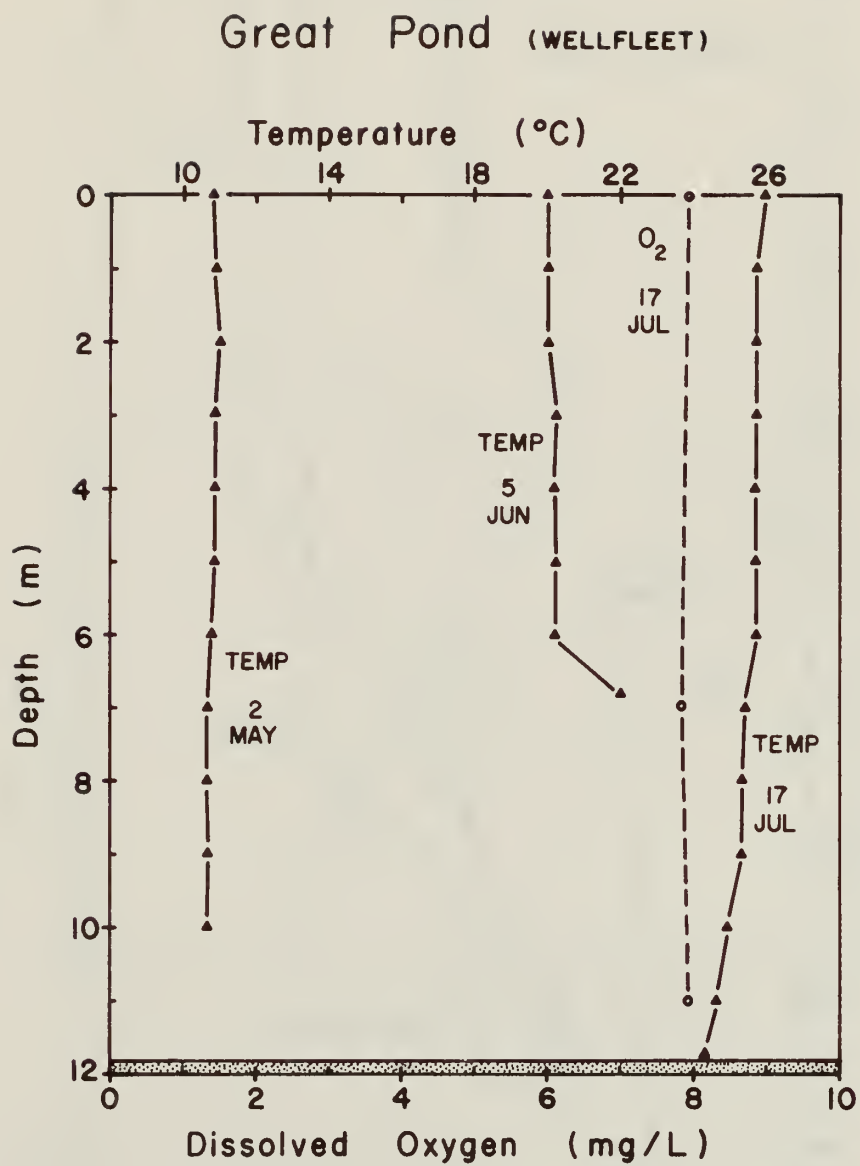
Figure 5. Temperature and DO in Great Pond (W).
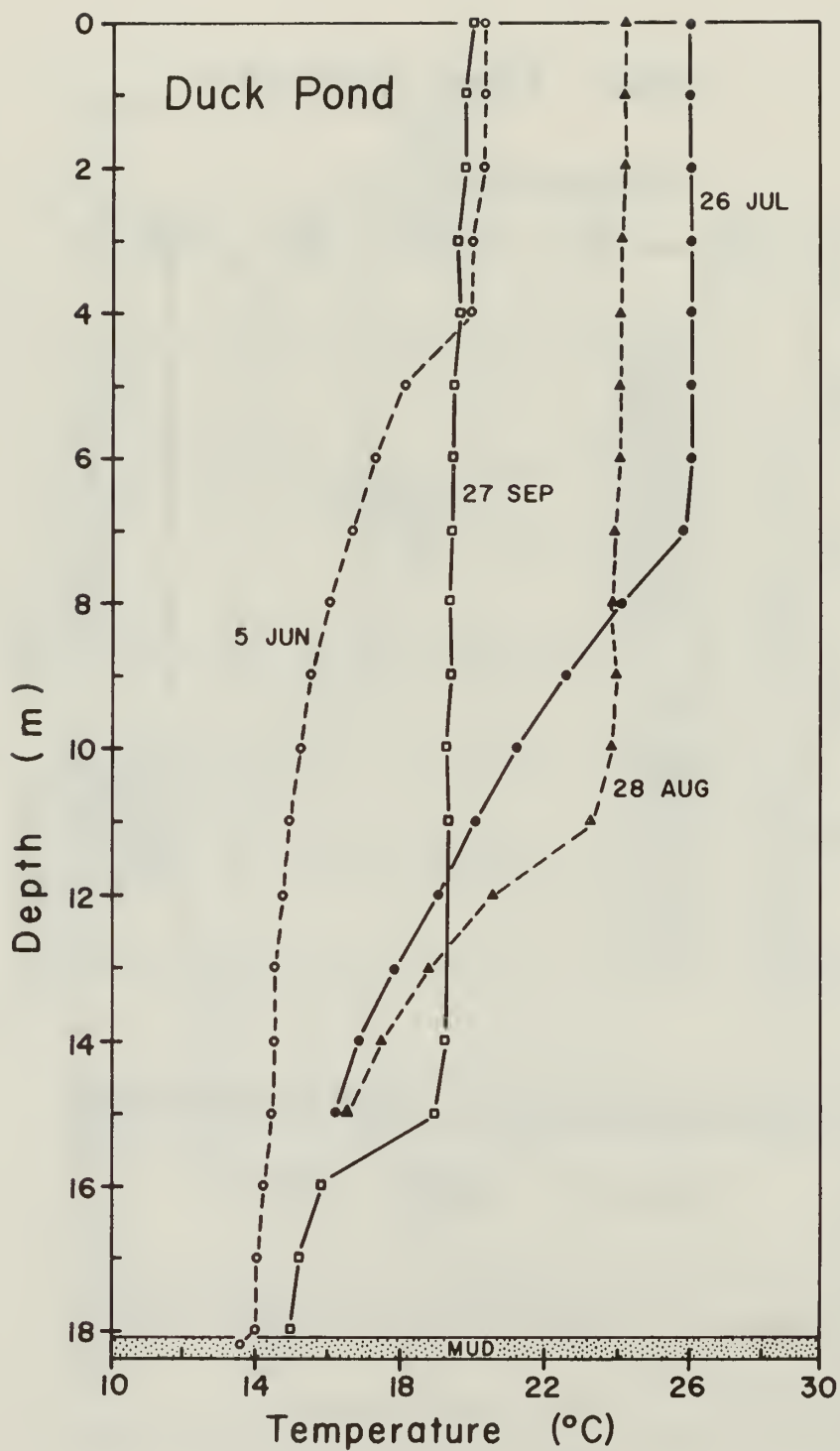
Figure 6. Temperature profiles in Duck Pond, 1975.
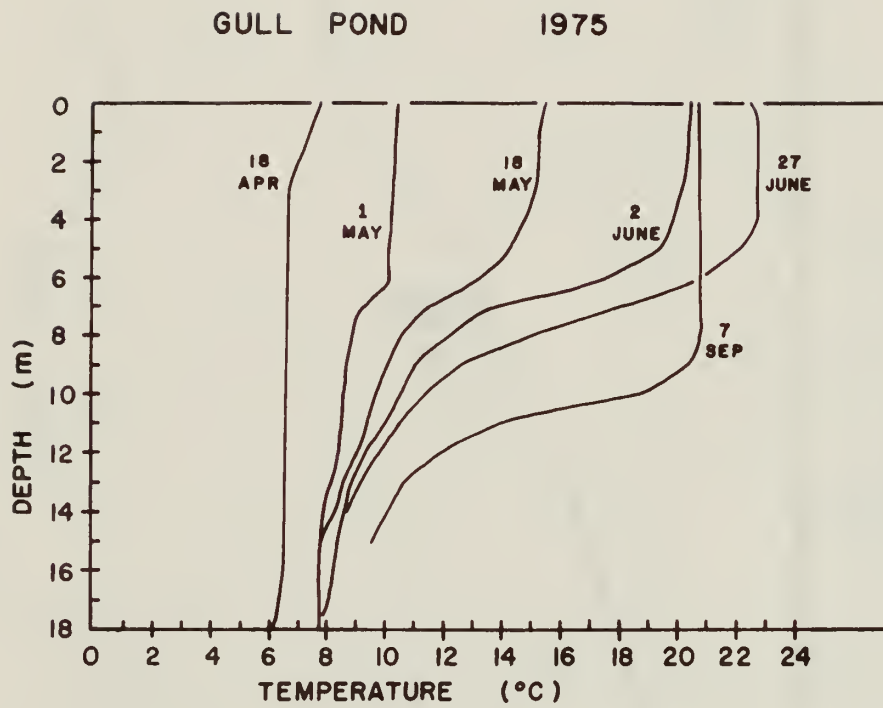
Figure 7. Temperature profiles in Gull Pond, 1975.
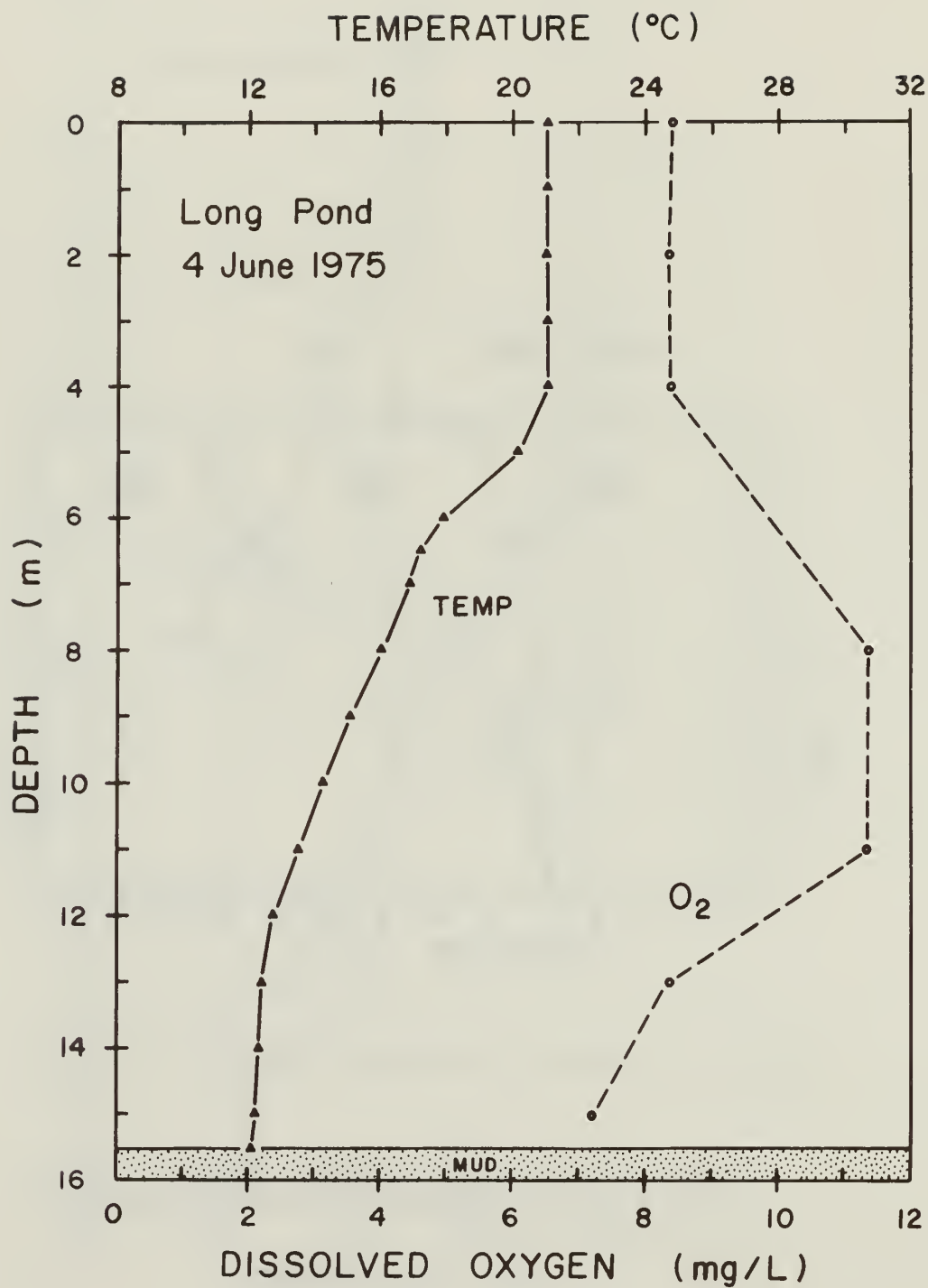
Figure 8. Temperature and DO profiles in Long Pond, 4 June 1975.
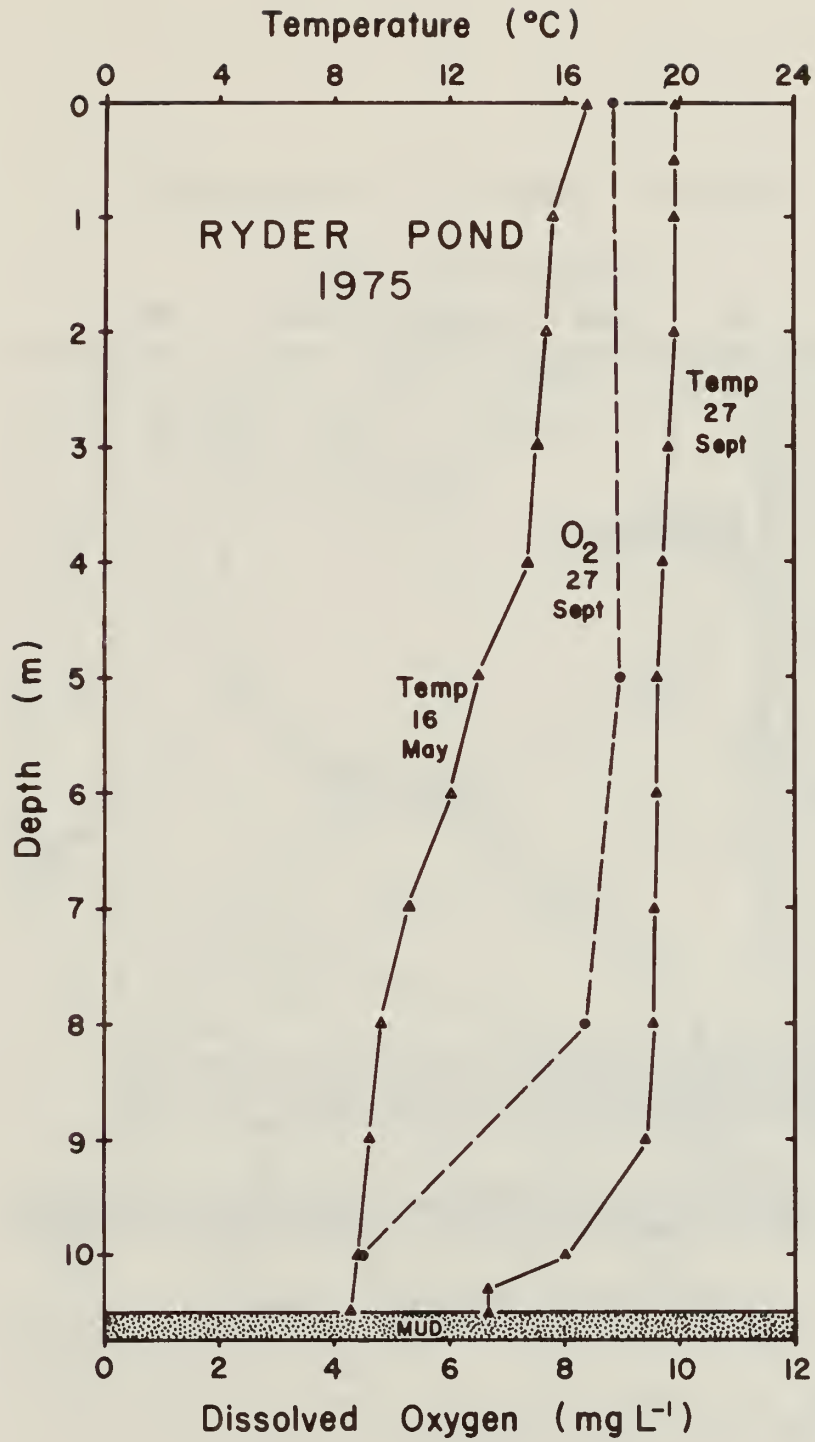
Figure 9. Temperature and DO profiles in Ryder Pond, 27 September 1975.
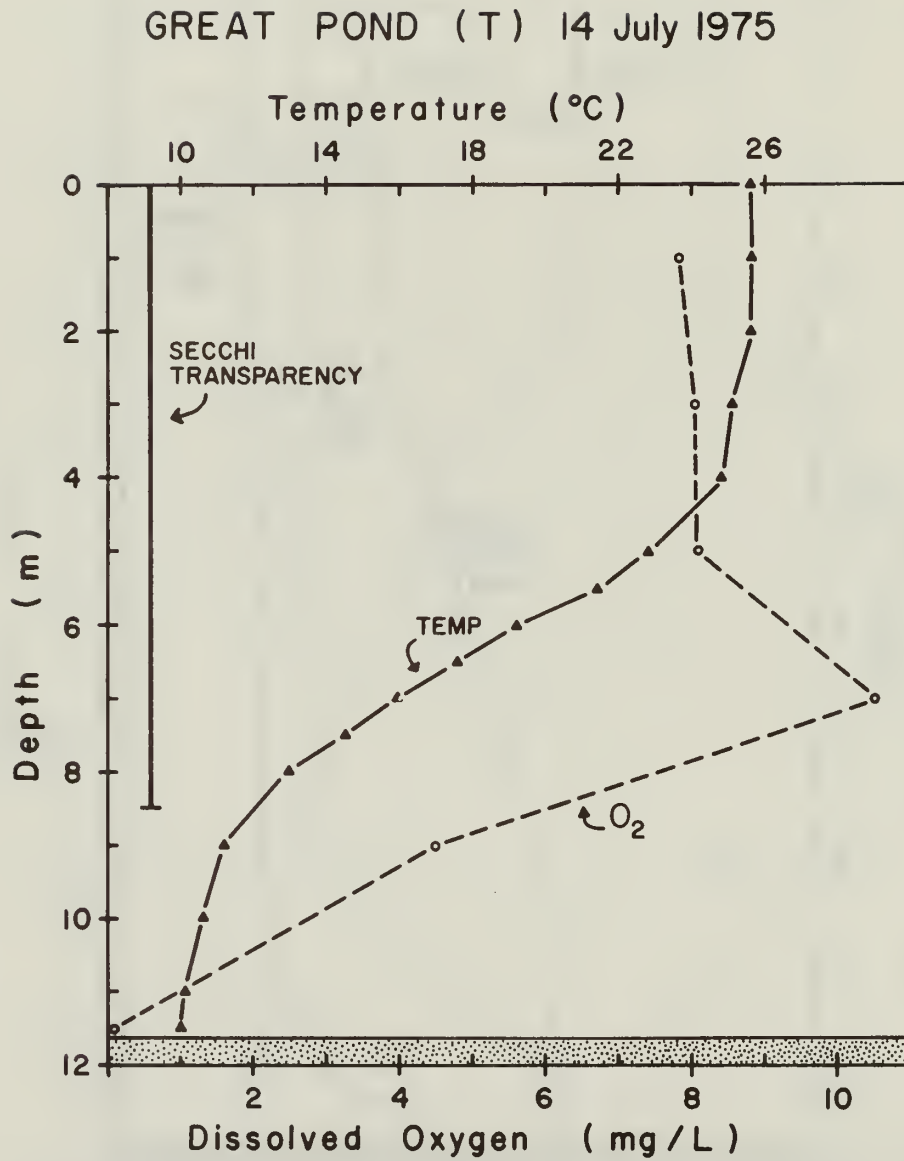
Figure 10. Temperature, DO, and Secchi transparency in Great Pond (T), 14 July 1975.
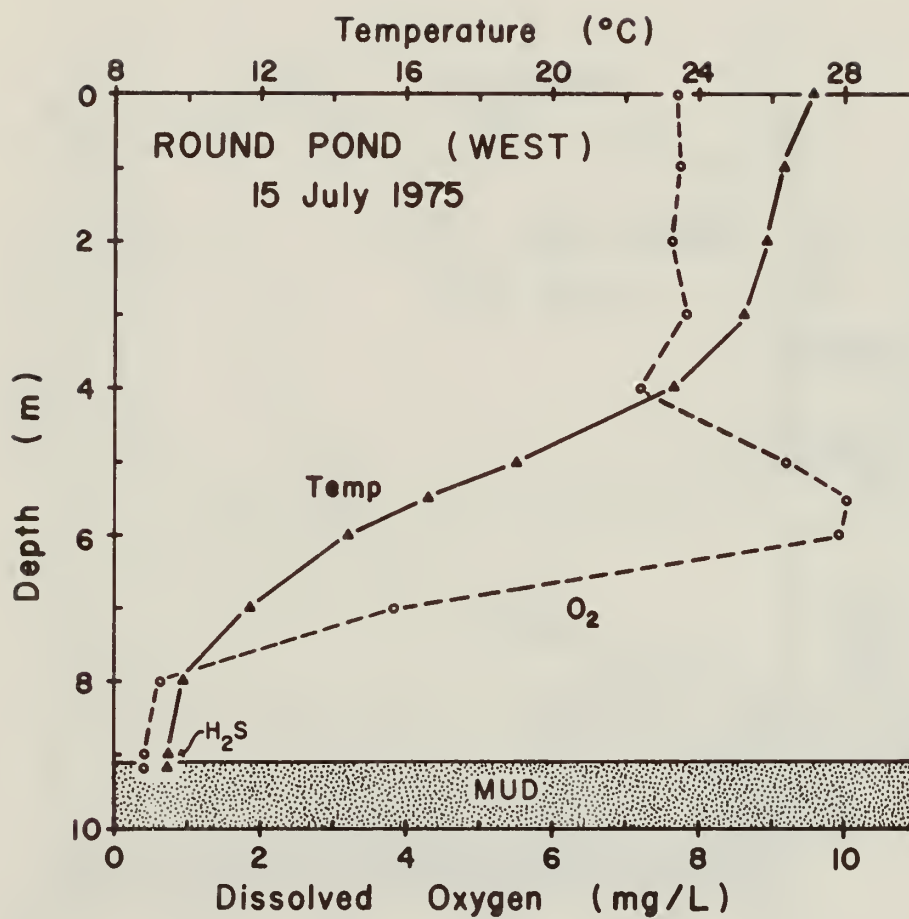
Figure 11. Temperature and DO profiles in Round Pond
(West), 15 July 1975. Hydrogen sulfide production was
noted in the 9 m sample.
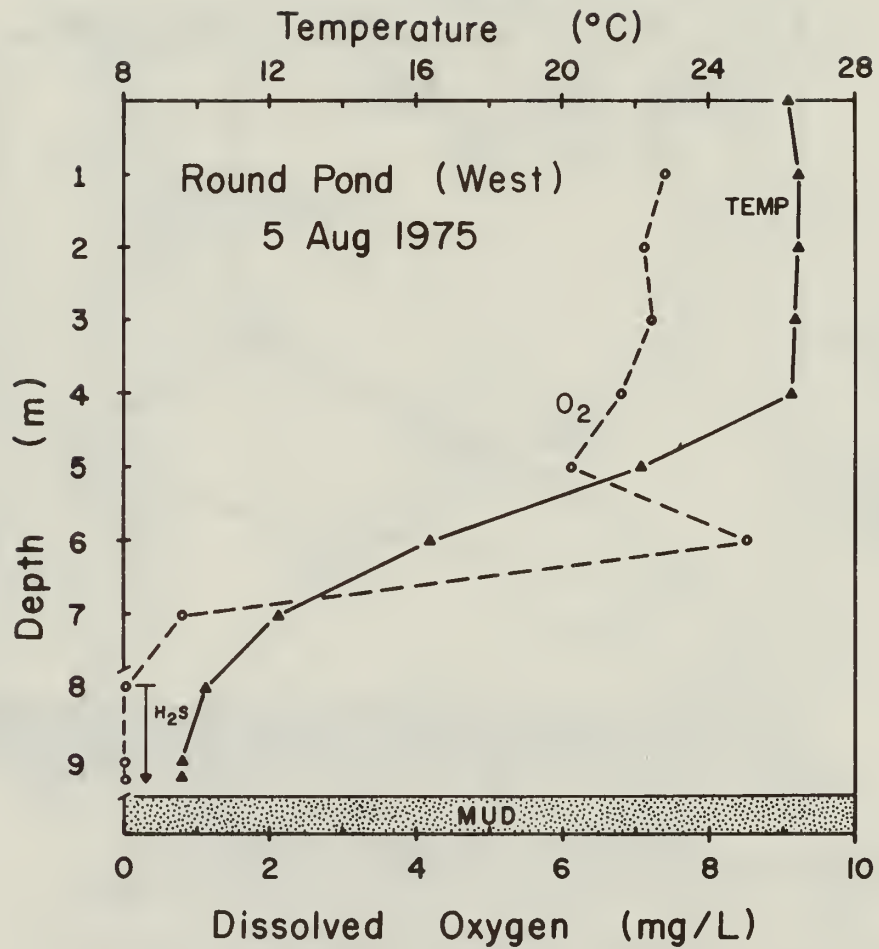
Figure 12. Temperature and DO profiles in Round Pond (West), 5 August 1975.
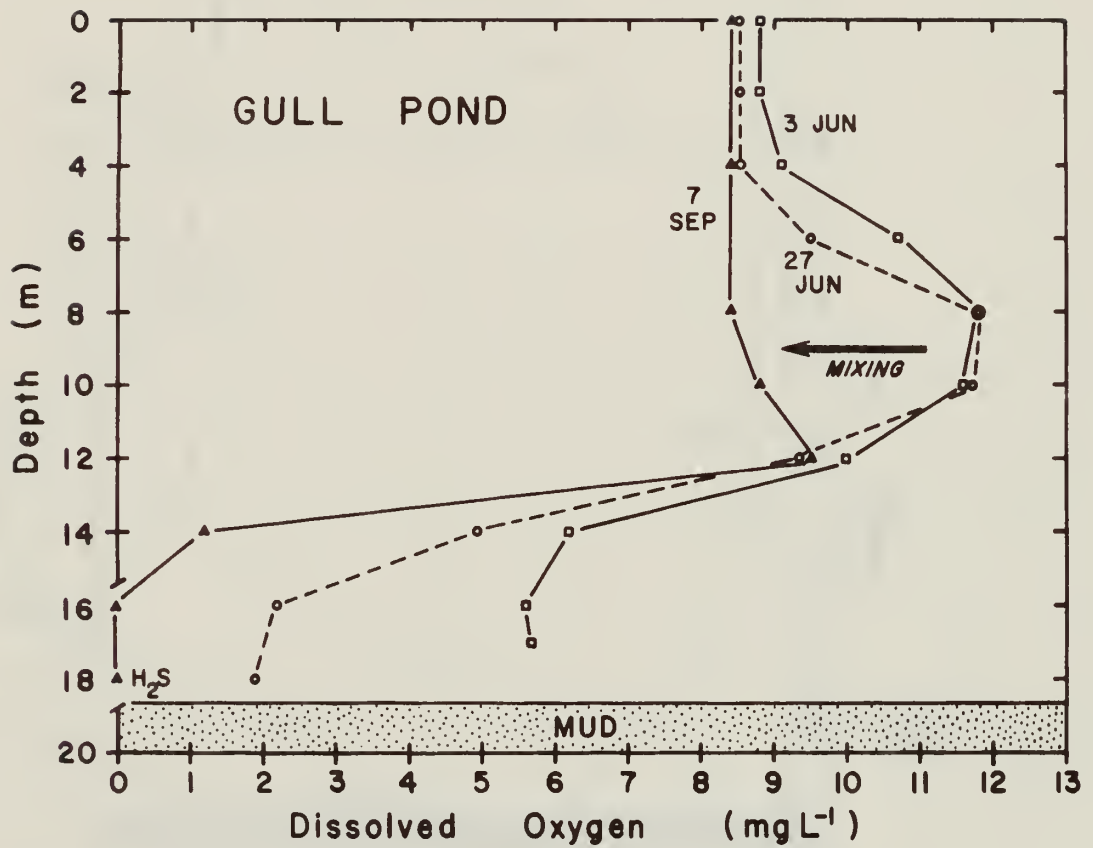
Figure 13. DO profiles in Gull Pond, summer 1975.
Note the removal of the metalimnetic maximum by
mixing in early September.
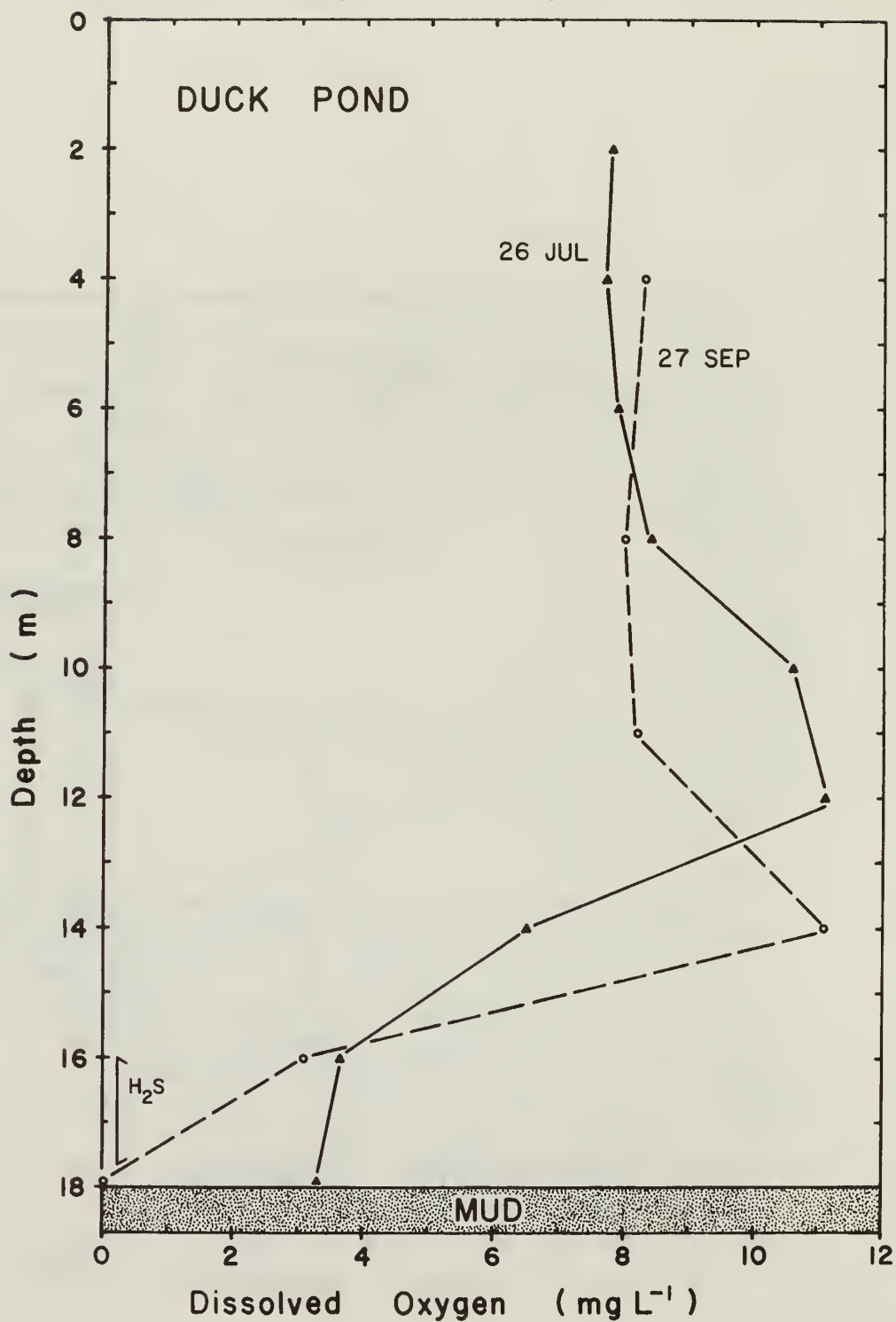
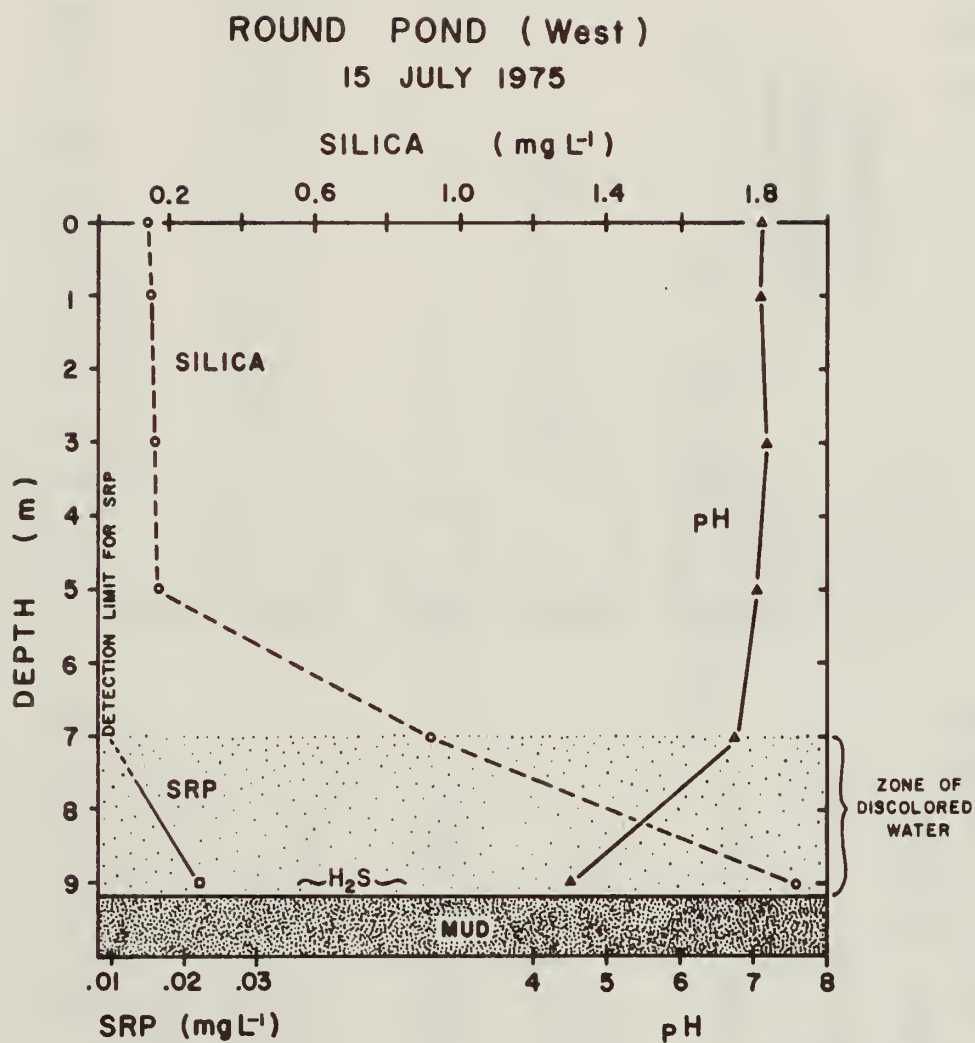Figure 14. DO profiles in Duck Pond, summer 1975. Hydrogen sulfide production was noted in the 16 m sample.

ROUND POND (West)
15 JULY 1975

Figure 15. Profiles of soluble reactive phosphate, pH, and dissolved silica in Round Pond (West), 15 July 1975.
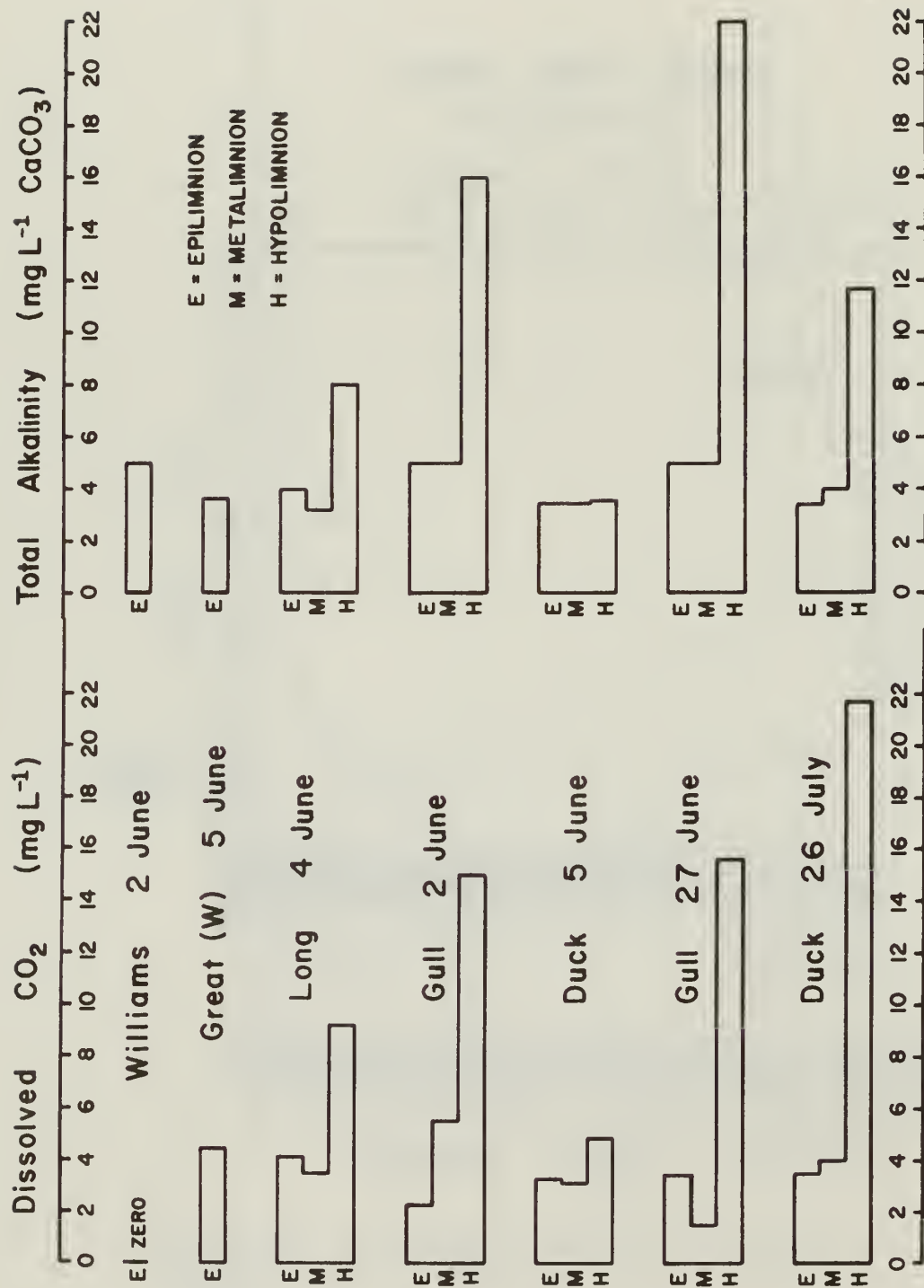
Figure 16. Free CO_2 and Total Alkalinity in strata of several CACO ponds, summer 1975.
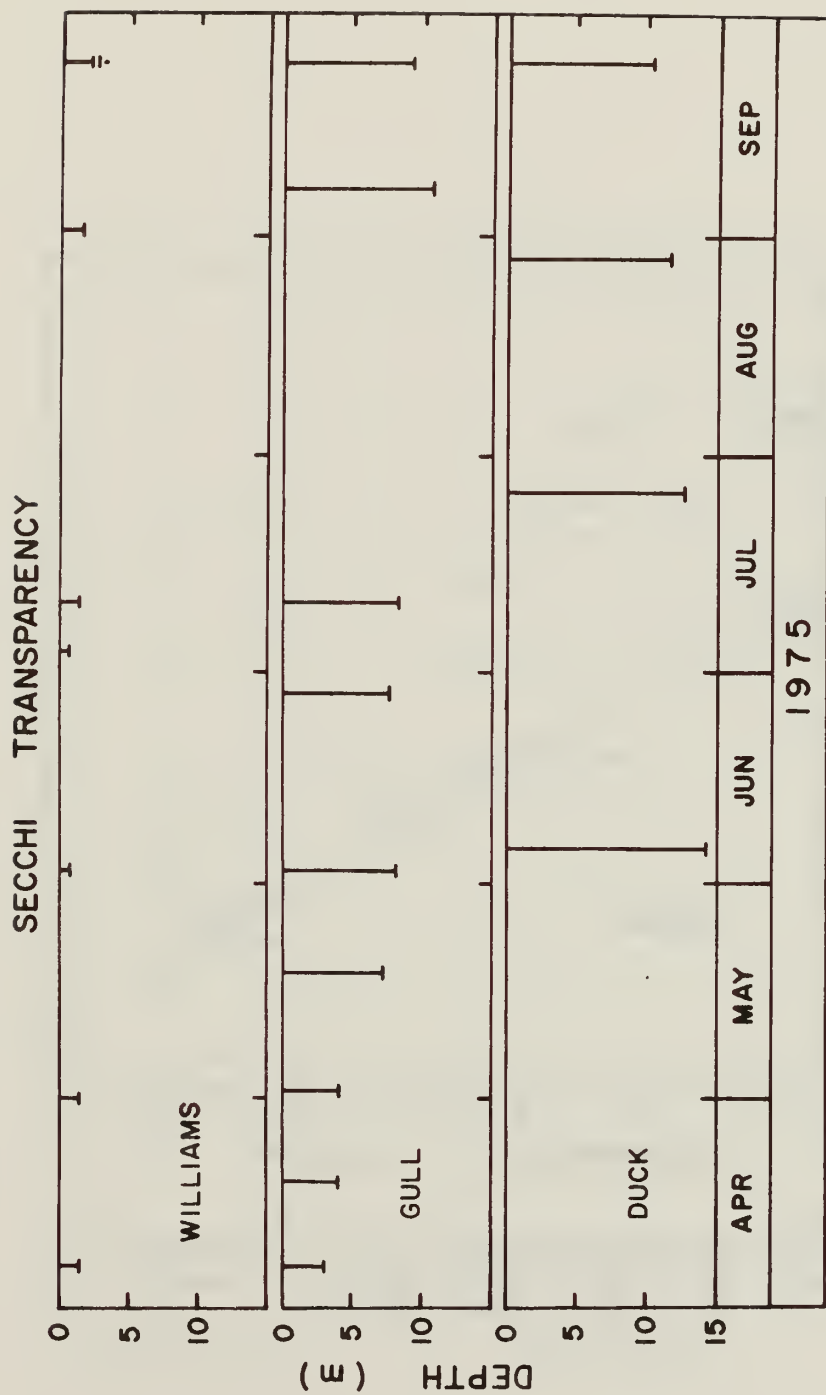
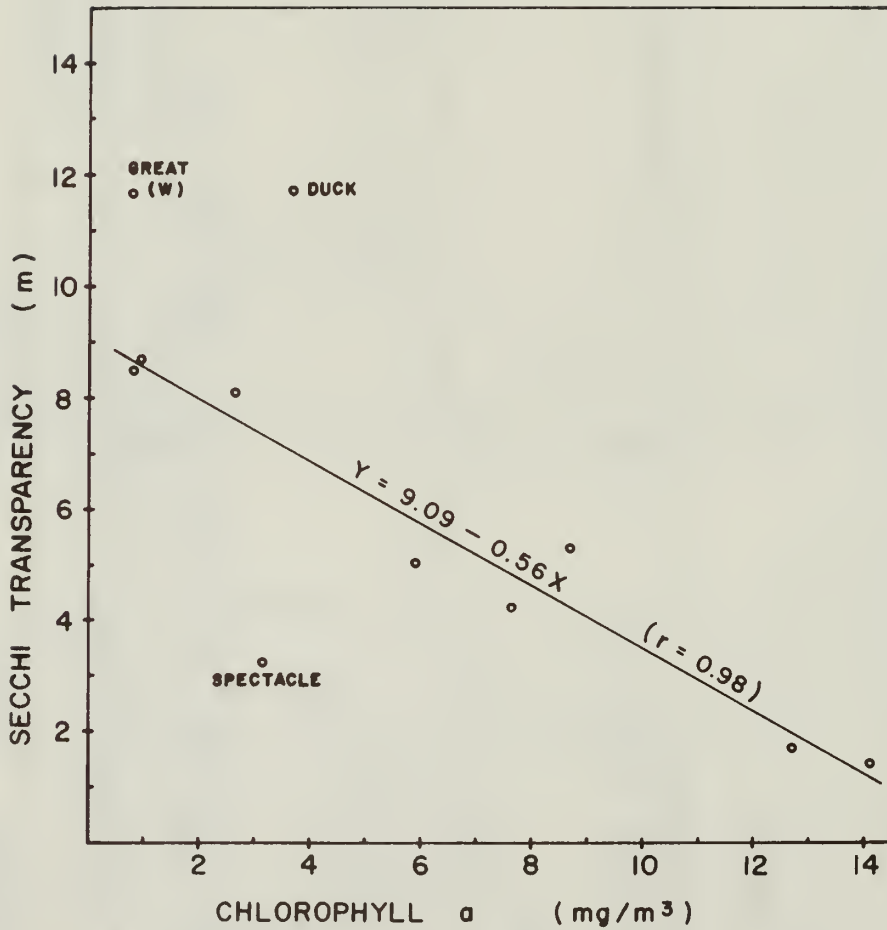Figure 17. Trends in Secchi transparency in Williams, Gull and Duck ponds, summer 1975.

Figure 18. The relationship of Secchi transparency with chlorophyll a concentration in CACO ponds, summer 1975. See text for details of regression line.
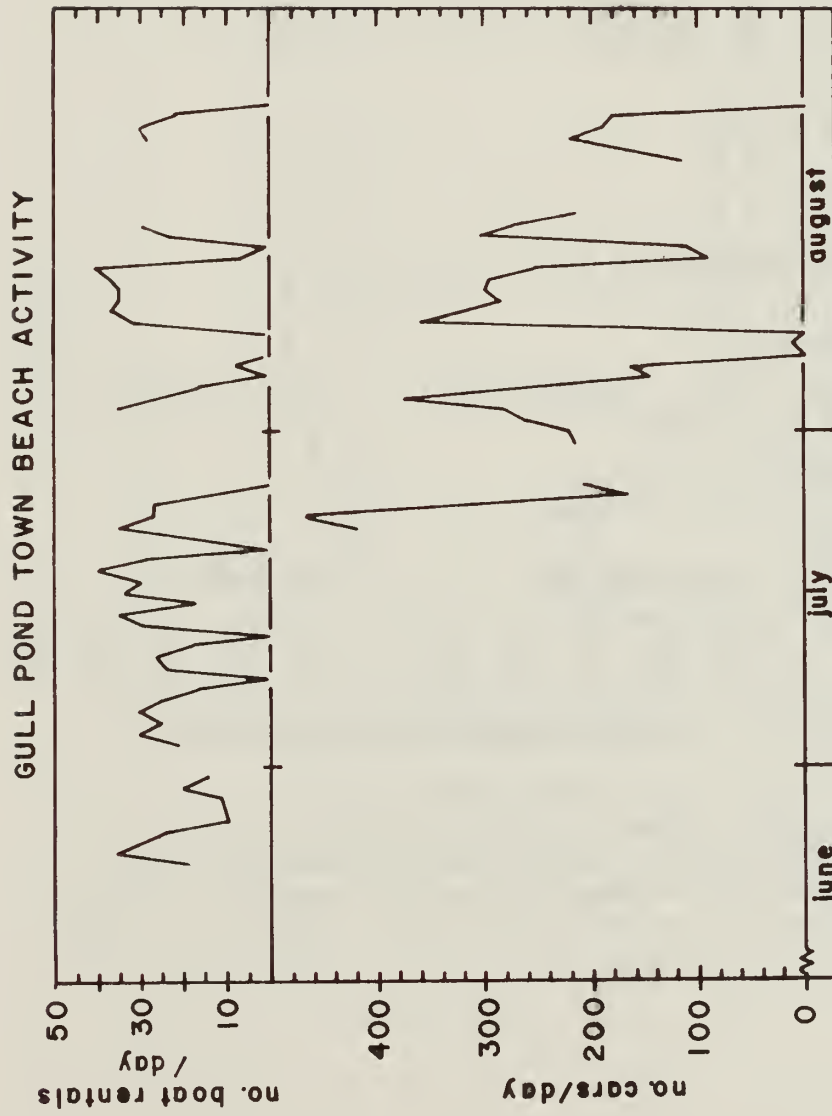
GULL POND TOWN BEACH ACTIVITY

Figure 19. Gull Pond public beach activity, as relected in boat rentals and numbers of vehicles entering the parking lot, summer 1975.
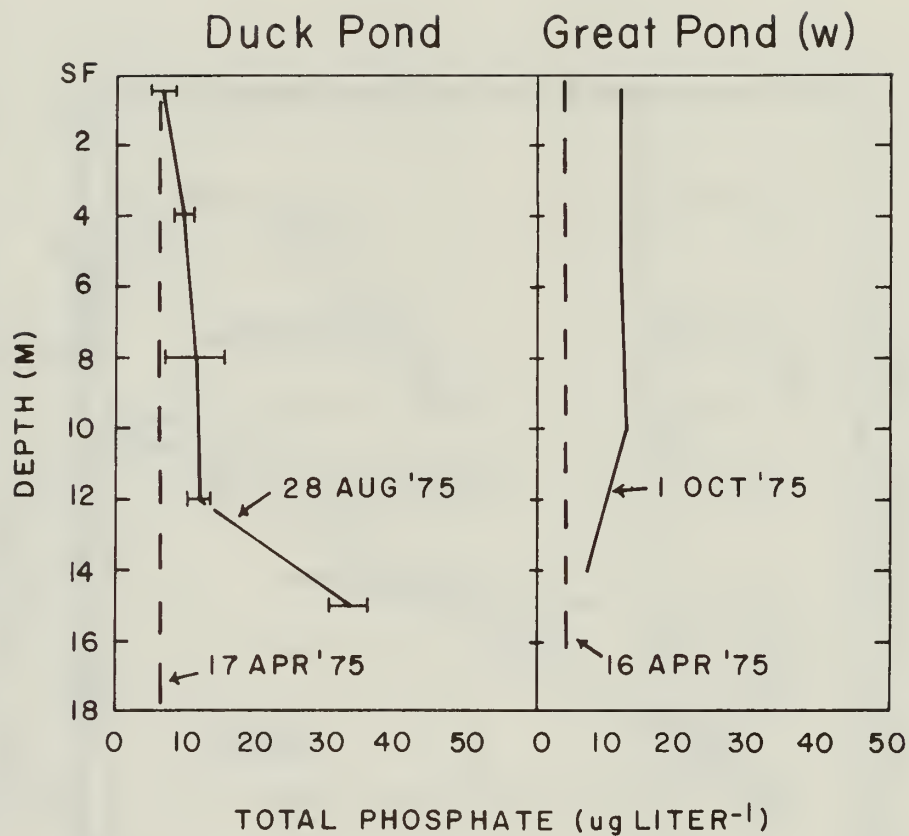
Figure 20. Change in total phosphate concentration
over the summer of 1975 in two oligotrophic kettle
ponds within the Cape Cod National Seashore.

Figure 21. Changes in total phosphate concentrations in the water column of Gull Pond (Cape Cod National Seashore) in 1975.
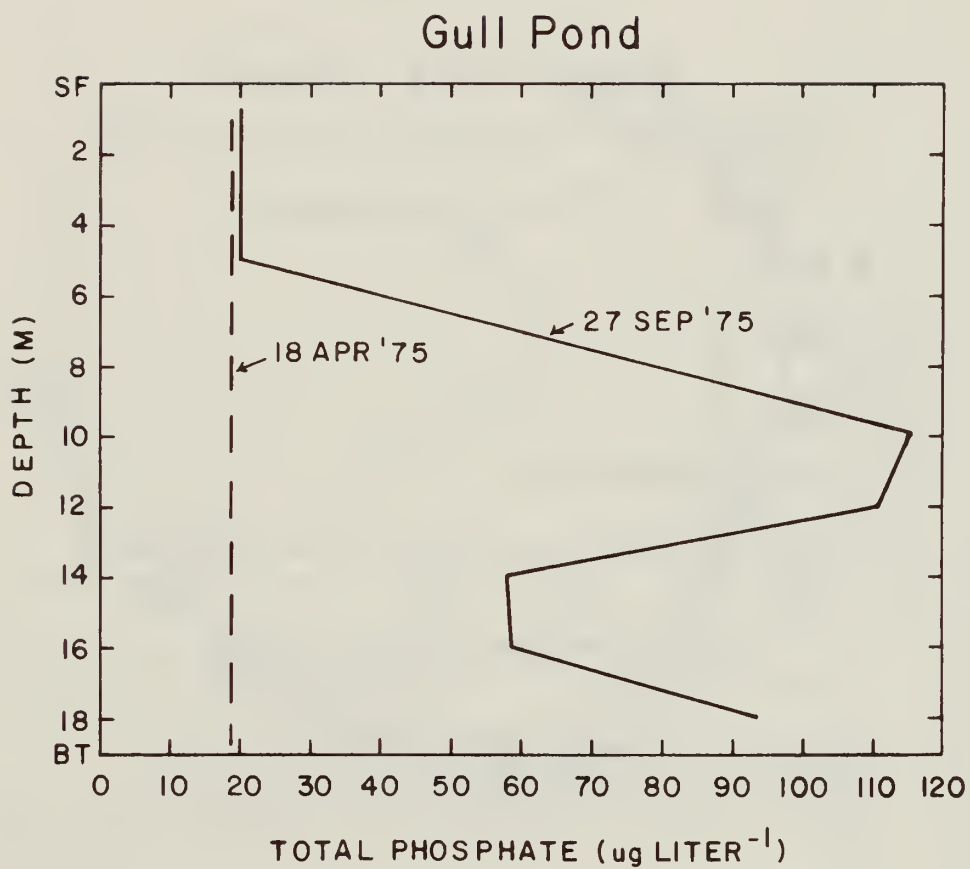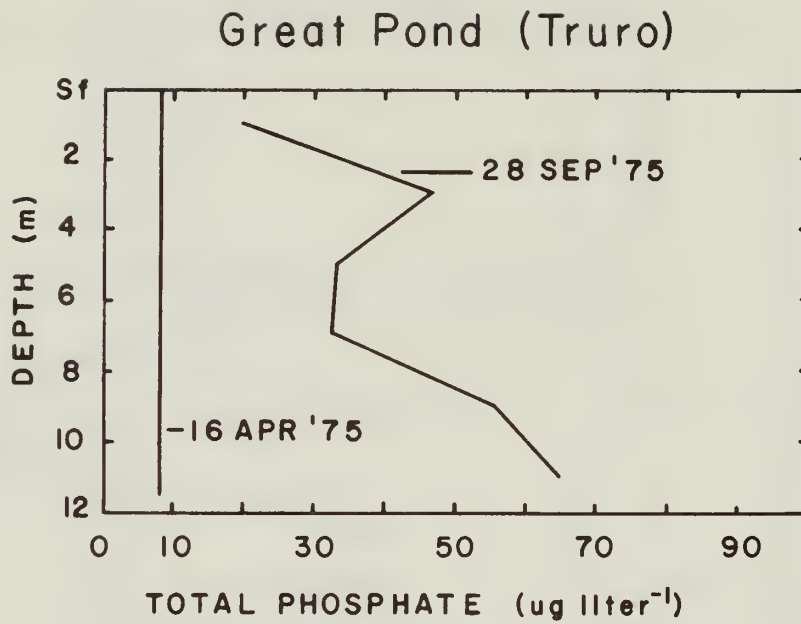
Great Pond (Truro)

Figure 22. Changes in total phosphate (as P)
concentrations in the water column of Great Pond
(Truro) (Cape Cod National Seashore) in 1975.
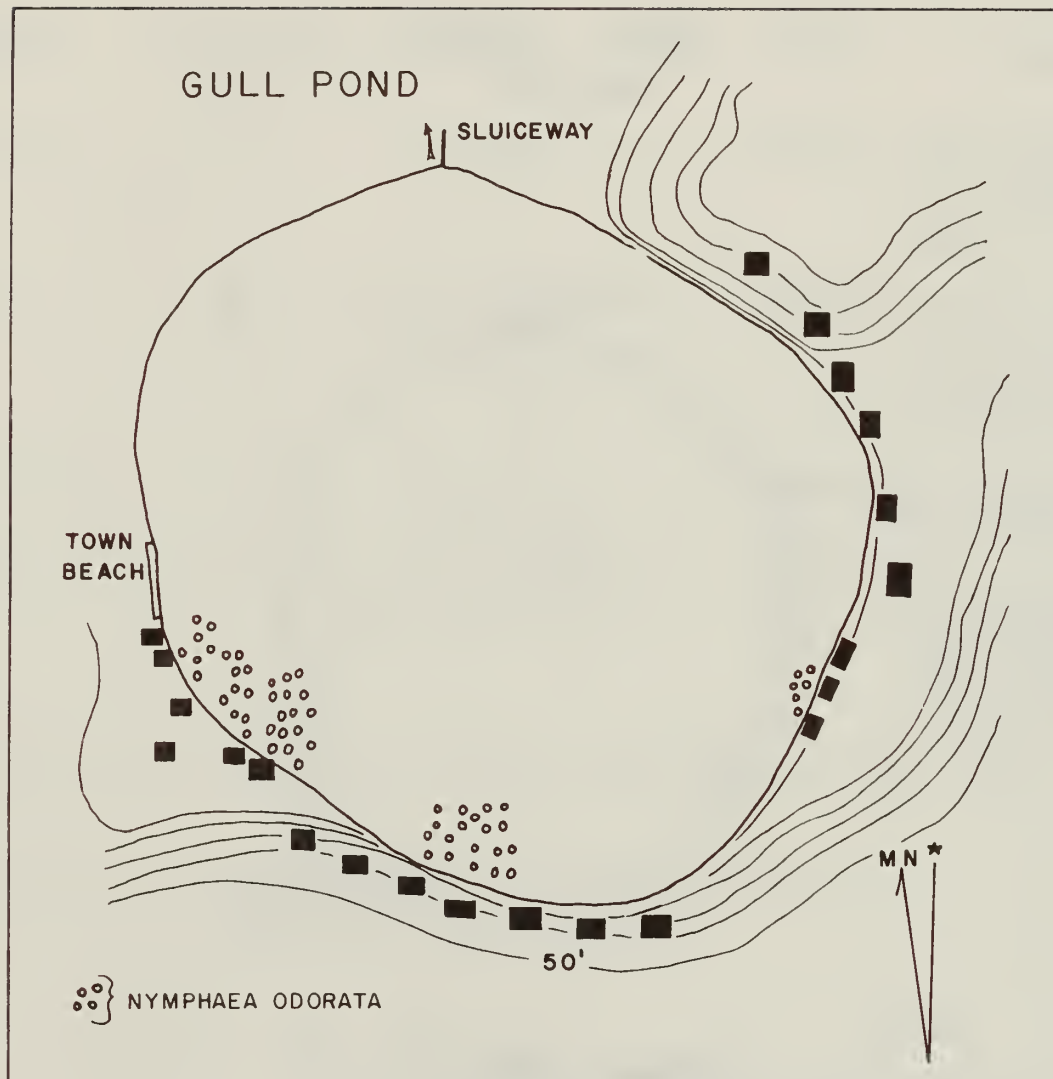
Figure 23. A sketch of Gull Pond showing the cottages most closely situated on its shoreline. Also noted are the locations of the major weedy areas.

DUCK   POND
Wellfleet

Figure 24. General location and direction of observed currents in Duck Pond, August 1975. Intermittent arrows indicate downward currents. See Table IX for data.

APPENDIX A: Technical Data for the Atomic Absorption Terminations

A.   ANALYTICAL SPECIFICATIONS (PERKIN-ELMER 403)

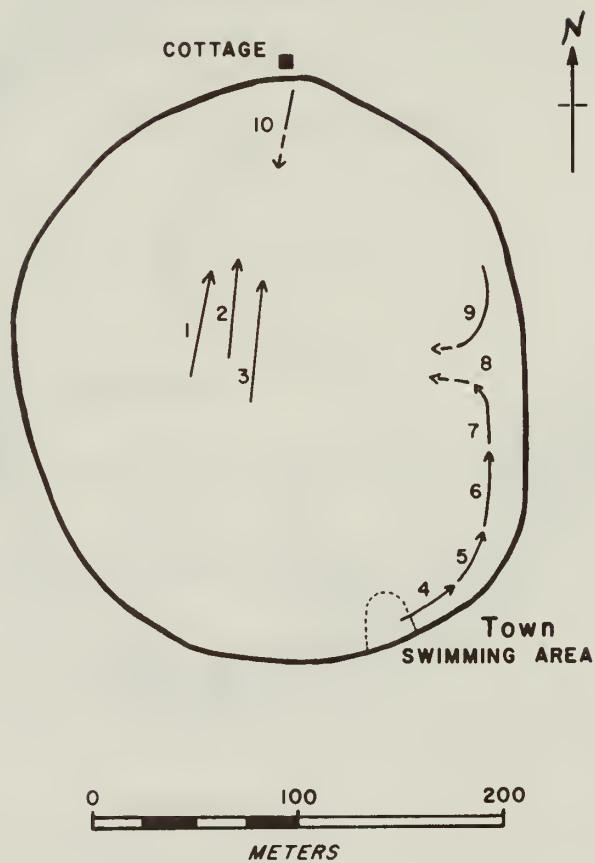| Element	Wavelength (nm)	Instrument Setting	Slit	Flame Type	Notes
Calcium	422.7	211 - VIS (214.2)*	4	reducing	adjust fuel flow for max. absorption for a Ca standard prior to analysis.
Iron	248.3	248 - UV (249) (249.9)*	3	oxidizing	iron has a double peak at this wavelength. the peak of 249.9 was used since there is less noise there.
Potassium	766.5	383 - VIS (385.7)*	4	oxidizing	a red filter was used which absorbs 650 nm.
Sodium	330.2	330 - UV (331.6)*	4	oxidizing	330.2 is a less sensitive wavelength, enabling a broader concentration of Na ions to fall into linear range.

* indicates the actual machine setting at which absorbance peak occurs.

B.   ADDITIONS REQUIRED TO OVERCOME ANALYTICAL INTERFERENCES.

   1. Ca, Fe, K Standards and Samples received:

Substance	Amount	Effect
Na (NaCl)	400 ppm	Overcome tendency of K to ionize in flame.
$LaCl_3$**	1 ml for every 20 ml of standard or sample	Masks interference of PO_4, SO_4, Al.
HNO3	0.15%	Standards received acid to match acid strength of preserved samples.

2. Na Standards and Samples received:

Substance	Amount	Effect
K (KCl)	400 ppm	Overcomes tendency of Na to ionize in flame.

C. Element concentrations in standards:

Ca: 1,   2,   4,   6,   8 p.p.m.

Fe: .05, 0.1, 0.5, 1.0, 2.0 p.p.m.

K: 0.1, 0.5, 1.0, 1.5, 2.0 p.p.m.

Na: 5,   10,   15,   20,   25 p.p.m.

** The $LaCl_3$ solution was prepared as follows: Dissolve 29 g La_2O_3 slowly in small portions in 250 ml conc HCL and dilute to 500 ml with dist. $H2_o$. Add 1 ml La soln for each 10 ml of standard or sample.

APPENDIX B:

Additional Total Phosphorus data for Cape Cod National Seashore Ponds
(See text for methods)

Pond	Location or Depth (m)	Date	Total Phosphorus (ug/liter)
Gull	Surface runoff	25 July 1975	37
	" "	"	67
Coastal Pond (on Ocean View Drive)	Surface	3 May 1975	19
Long	1 m	1 Feb 1976	5
	3 m		5
	6 m		13
	14 m		5
Great (T)	4 m	1 Feb 1976	5
Great (T)	Surface	25 Mar 1976	8
Higgins	"	"	26
Northeast	"	"	9
Turtle	"	"	16
Southeast	"	"	9
Great (W)	"	"	4
Horseleech	"	"	12
Ryder	"	"	7
Kinnecum	"	"	9
Spectacle	"	"	6
Slough	"	"	9
Round (E)	"	"	7
Round (W)	2 m	"	13
Round (W)	9 m	"	16
Snow	Surface	"	10
Herring	"	"	24
Long	"	"	5
Dyer	"	26 Mar 1976	8
Duck	2 m	"	4
	17 m	"	4
Gull	2 m	"	15
	18 m	"	17

Appendix C : Inventory of cottages around the shoreline of Gull Pond (by S. Danos, summer 1976).

House #	Average # of Occupants	Period of use	Type of Sewerage System	Age of system (yr)	Location of System /distance from pond	Laundry Facilities on Premises	Phosphate-based detergent usage
1	5	Summer	Cesspool	20	Behind house/ <12m	No	--
2	5	Summer	Cesspool	20	S. East side/ <12m	No	Some
3	4	Summer	n.d.	n.d.	n.d.	n.d.	n.d.
4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
5	4	Summer	n.d.	20	n.d.	Yes	Yes
6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
7	2	year-round	Cesspool	20	east side/ 30m	Yes	Yes
8	4	Summer	Cesspool	17	south side	No	--
9	3	Summer	n.d.	n.d.	n.d.	No	--
10	2	year-round	Cesspool	4	east side/ 25m	Yes	Yes
11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
12	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
14	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
15	4	Summer	n.d.	Old	in front of house/ <10m	No	--
16	3 - 5	year-round	2 septic tanks 2 cesspools	3 / 20	behind house/ <20m	Yes	Not any more
17	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
18	1	year-round	septic tank	20	<30m	No	--
19	5	Summer	septic tank	20	behind house/ <20m	No	Yes
20	2	Summer	2 septic tanks	23	south side of house/ 15m	Yes	No
21	6	Summer ,some winter	2 septic tanks	10 / 20	behind house/ 20m	Yes	No

APPENDIX D:

Sodium, and Chloride concentrations, and Cl:Na ratios for Cape Cod National Seashore ponds. Analyses by S. Danos.

Samples for sodium determination were collected on June 27, 1976 by wading 1.5 m into the water and obtaining a representative sample appeoximately 0.5 m from the surface.

Results are as follows:

Pond	Sodium (mg/1)	Chloride (mg/1)	Cl:Na Ratio
Round (W)	9.4	19.5	2.08
Kinnacum	11.0	21.8	1.99
Snow	11.6	21.8	1.88
Long	12.6	23.2	1.85
Duck	13.8	25.0	1.82
Southeast	13.8	26.5	1.92
Northeast	14.2	27.2	1.92
Round (E)	15.0	27.2	1.82
Great (W)	15.2	29.2	1.93
Spectacle	15.4	29.0	1.89
Slough	16.0	30.5	1.91
Ryder	16.9	32.5	1.93
Gull	17.4	32.8	1.89
Higgins	17.4	33.8	1.95
Great (T)	17.7	33.5	1.90
Herring	18.0	33.5	1.87
Horseleach	21.8	41.8	1.92
Williams	22.3	41.8	1.88